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CLAIMS

[Claim(s)]

[Claim 1]A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate.

A p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated.

Are the above the nitride semiconductor device which it had, and said p side clad

layer, It has thickness of 100A or less at not less than 10A, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[Claim 2]The nitride semiconductor device according to claim 1 by which a p type impurity was doped by either [at least] said 1st layer or said 2nd layer.

[Claim 3]The nitride semiconductor device according to claim 2 from which concentration of a p type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 4]The nitride semiconductor device according to claim 2 or 3 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 5]A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p

side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one. The 1st layer that consists of a nitride semiconductor which has thickness of 100A or less at not less than 10A, and does not contain aluminum, A nitride semiconductor device, wherein the 2nd layer that consists of a nitride semiconductor which a presentation differs from this 1st layer, and has thickness of 100A or less at not less than 10A, and contains aluminum is the laminated superlattice layers.

[Claim 6]A nitride semiconductor device of Claim 5 by which said p side clad layers are said superlattice layers, and a p type impurity was doped by either [at least] said 1st layer or said 2nd layer.

[Claim 7]The nitride semiconductor device according to claim 6 from which concentration of a p type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 8]The nitride semiconductor device according to claim 7 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 9]A nitride semiconductor device of Claim 5 by which said n side clad

layers are said superlattice layers, and a n type impurity was doped by either [at least] said 1st layer or said 2nd layer.

[Claim 10]The nitride semiconductor device according to claim 9 from which concentration of a n type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 11]The nitride semiconductor device according to claim 10 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 12]The nitride semiconductor device according to claim 1 to 11 in which said 2nd layer is a nitride semiconductor expressed with formula $aluminum_{Y}Ga_{1-Y}N$ (however, $0< Y<=1$).

[Claim 13]Said 1st layer consists of a nitride semiconductor expressed with formula $In_{X}Ga_{1-X}N$ ($0<=X<=1$) in said superlattice layers, And the nitride semiconductor device according to claim 12 which said 2nd layer becomes from a nitride semiconductor expressed with formula $aluminum_{Y}Ga_{1-Y}N$ (however, $0< Y<=1$).

[Claim 14]Said 1st layer consists of a nitride semiconductor expressed with formula $In_{X}Ga_{1-X}N$ ($0<=X<1$) in said superlattice layers, And the nitride

semiconductor device according to claim 13 which said 2nd layer becomes from a nitride semiconductor expressed with formula aluminum$_Y$Ga$_{1-Y}$N (however, 0< Y<1).

[Claim 15]A nitride semiconductor device given in any 1 clause of the Claims 1-14 which said 1st layer and said 2nd layer become from a nitride semiconductor which has thickness of 70A or less, respectively.

[Claim 16]A nitride semiconductor device given in any 1 clause of the Claims 1-15 whose thickness of said p side contact layer is 500A or less.

[Claim 17]The nitride semiconductor device according to claim 16 whose thickness of said p side contact layer is 300A or less and not less than 10A further.

[Claim 18]A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100A or less at not less than 10A, and does

not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, The 3rd layer that consists of a nitride semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A nitride semiconductor device, wherein the 4th layer that consists of a nitride semiconductor which a presentation differs from this 3rd layer, and has thickness of 100A or less at not less than 10A, and contains aluminum is the laminated superlattice layers.

[Claim 19]The nitride semiconductor device according to claim 18 by which a Mine-like ridge part was formed in a resonant direction in a layer currently formed above said p side clad layer and this p side clad layer.

[Claim 20]A nitride semiconductor device given in any 1 clause of the Claims 1-19 which have a nitride semiconductor with which said active layer contains indium.

[Claim 21]Said nitride semiconductor device is a nitride semiconductor device given in any 1 clause among Claims 1-20 currently formed on C side of silicon on sapphire.

[Claim 22]It is a nitride semiconductor device given in any 1 clause among Claims 1-20 currently formed on a GaN board from which silicon on sapphire was removed after said nitride semiconductor device grows up a GaN layer which doped Si on C side of silicon on sapphire.

[Claim 23]Said n side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-22 as for which GaN exists.

[Claim 24]Said n side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-22 which are InGaN.

[Claim 25]Said p side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-24 which are GaN.

[Claim 26]Said p side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-24 which are InGaN.

[Claim 27]Said nitride semiconductor device touches said active layer, and it has the p side cap layer which consists of a nitride semiconductor containing aluminum, It is a nitride semiconductor device given in any 1 clause among Claims 1-26 which have the p side light guide layer in which bandgap energy is smaller than said p side cap layer in a position which is separated from an active

layer rather than the p side cap layer.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention]This invention Light emitting devices, such as LED (light emitting diode) and LD (laser diode), It is related with the element which consists of a nitride semiconductor ($In_XAl_YGa_{1-X-Y}N$, 0<=X, 0<=Y, X+Y<=1) used for electron devices, such as photo detectors, such as a solar cell and a photosensor, or a transistor. a layer which general formula $In_XGa_{1-X}N$, $aluminum_YGa_{1-Y}N$, etc. which are used in this Description only show the empirical formula of a nitride semiconductor layer, and is different -- for example, even if shown by the same general formula, It is not shown till the X value of those layers and Y value being in agreement.

[0002]

[Description of the Prior Art]The nitride semiconductor was just put in practical use with a full color LED display, a traffic signal, etc. as a material of

high-intensity blue LED and authentic green LED recently. LED used for these various devices has terrorism structure to the double into which the active layer which consists of InGaN of single quantum well structure (SQW:Single-Quantum- Well) between a n type nitride semiconductor layer and a p type nitride semiconductor layer was inserted. Wavelength, such as blue and green, is determined by fluctuating In composition ratio of an InGaN active layer.

[0003]These people announced the 410-nm laser oscillation in the room temperature for the first time under pulse current in the world recently using this material (for example, Jpn.J.Appl.Phys. Vol35 (1996) pp.L74-76). This laser device is the conditions of 2 microseconds of pulse width, and 2 ms of pulse cycles, and shows the threshold current of 610 mA, threshold current density 8.7 kA/cm^2, and a 410-nm oscillation. The threshold current announced the improved low laser device further again in Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, and p.1477-1479. This laser device has the structure where the ridge stripe was formed in a part of p type nitride semiconductor layer.

1 microsecond of pulse width, 1 ms of pulse cycles, and 0.1% of duty ratio show the threshold current of 187 mA, threshold current density 3 kA/cm^2, and a 410-nm oscillation.

[0004]

[Problem to be solved by the invention]The blue and green LED which consist of nitride semiconductors are forward current (If)20mA, and compared with red LED which forward voltage (Vf) becomes from the semiconductor of 3.4V - those with 3.6V, and a GaAlAs system, as for more than 2V, since it is high, a fall of further Vf is desired. In LD, the current in a threshold value and voltage are still high, and in order to carry out continuous oscillation at a room temperature, it is necessary to realize the element that this threshold current and voltage fall and that power efficiency is still higher.

[0005]Therefore, by reducing the current in the threshold value of the LD element which mainly consists of nitride semiconductors, and voltage, the place made into the purpose of this invention realizes continuous oscillation, and reduces Vf in a LED element, is reliable, and there is in realizing the nitride semiconductor device excellent in power efficiency.

[0006]

[Means for solving problem]As a result of examining a nitride semiconductor device wholeheartedly that the p type layer which sandwiched the active layer,

and/or a n type layer should be improved, this invention persons by using superlattice layers for the p type layer except an active layer, and/or a n type layer, The crystallinity of the layer using superlattice layers can be made good, and it newly finds out that said problem is solvable, and came to accomplish this invention.

[0007]Namely, the 1st nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor which said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers. Since the resistance of the p type nitride semiconductor layer which consists of said superlattice layers can be made very low by this, power

efficiency of a nitride semiconductor device can be made high. In the 1st nitride semiconductor device concerning this invention, said superlattice layers, Since the 2nd layer that consists of a nitride semiconductor which the 1st layer, this 1st layer, and presentation which consist of a nitride semiconductor which has thickness of 100A or less differ from each other, and has thickness of 100A or less is laminated, the crystallinity of said superlattice layers can improve. the threshold current by applying a superstructure to a p type cladding layer, and voltage -- it seems to be low -- ****** can be large and a threshold current and voltage can be notably reduced in this invention.

[0008]It is preferred to dope a p type impurity in the 1st nitride semiconductor device concerning this invention in either [at least] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 1st nitride semiconductor device of the above, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0009]The 2nd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad

layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one. It has thickness of 100A or less at not less than 10A, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0010]In the 2nd nitride semiconductor device concerning this invention, when said p side clad layers are said superlattice layers, It is preferred to dope a p type impurity in either [at least] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 2nd nitride semiconductor device concerning this invention, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0011]In the 2nd nitride semiconductor device concerning this invention, when said n side clad layers are said superlattice layers, It is preferred to dope a n type impurity in either [at least] said 1st layer or said 2nd layer, and it is preferred that the concentration of the n type impurity doped without the 1st layer of an account and said 2nd layer differs mutually. Under the present circumstances, when the bandgap energy of said 1st layer and said 2nd layer differs mutually, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0012]The 3rd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, The 3rd layer that consists of a nitride

semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 3rd layer, and it has thickness of 100A or less at not less than 10A, and the 4th layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0013]It may be made to form a Mine-like ridge part in a resonant direction in the 3rd nitride semiconductor device of the above in the layer currently formed above said p side clad layer and this p side clad layer.

[0014]In the 1st concerning this invention - the 3rd nitride semiconductor device, said active layer may have a nitride semiconductor containing indium. Said 1st [the] - the 3rd nitride semiconductor device, It may be made to form on C side of silicon on sapphire, and after said 1st [the] - the 3rd nitride semiconductor device grow up the GaN layer which doped Si on C side of silicon on sapphire, it may be made to form them on the GaN board from which silicon on sapphire was removed. In said 1st [the] - the 3rd nitride semiconductor device, said n side light guide layer may be GaN, and may be InGaN. In said 1st [the] - the 3rd

nitride semiconductor device, said p side light guide layer may be GaN, and may be InGaN. Said active layer is touched in said 1st [the] - the 3rd nitride semiconductor device, It is preferred to provide the p side light guide layer in which bandgap energy is smaller than said p side cap layer in the position which has the p side cap layer which consists of a nitride semiconductor containing aluminum, and is separated from an active layer rather than the p side cap layer.

[0015]The 1st layer that consists superlattice layers of $In_XGa_{1-X}N$ (0<=X<=1) in the 1st - the 3rd nitride semiconductor device of this invention, If constituted by laminating the 2nd layer that consists of $aluminum_YGa_{1-Y}N$ (0<=Y<=1, X=Y!=0), General formula $aluminum_YGa_{1-}$ Since a good crystalline semiconductor layer is obtained, the nitride semiconductor expressed with $_YN$ and $In_XGa_{1-X}N$ can form a layer with few crystal defects. Thereby, the crystallinity of the whole nitride semiconductor becomes good, and when improvement (improvement in power efficiency) and this element are a LED element or an LD element about the output of this element, Vf, a threshold current, voltage, etc. can be made low. In the 1st of this invention - the 3rd nitride semiconductor device. In said superlattice layers in order to form a layer with still few crystal defects, It is still more preferred that said 1st layer consists of a nitride semiconductor expressed with formula $In_XGa_{1-X}N$ (0<=X<1), and said 2nd

layer consists of a nitride semiconductor expressed with formula $aluminum_{Y}Ga_{1-Y}N$ (0< Y<1).

[0016]In the 1st - the 3rd nitride semiconductor device of this invention, although it is preferred that it is 70A or less as mentioned above as for the thickness of said 1st layer and the 2nd layer, it is set as 40A or less still more preferably. In this invention, the thickness of said 1st layer and the 2nd layer is set as not less than 10A. By setting up within the limits of this, nitride semiconductor layers, such as $aluminum_{Y}Ga_{1-Y}N$ (0< Y<=1) which was hard to grow up, can form with sufficient crystallinity by the former. Of the p type nitride semiconductor layers which are between p electrode and an active layer especially, at least further, And/or, when making into superlattice layers at least one layer in the n type nitride semiconductor layer between n side contact layer as a current injection layer and the active layer in which n electrode is formed, the effect by setting the 1st layer that constitutes the superlattice layers, and the 2nd layer as said thickness is large.

[0017]In the 1st - the 3rd nitride semiconductor device of this invention, it is preferred to have p side contact layer for forming p electrode, and to set the thickness of these p side contact layers as 500A or less. Thus, the resistance of

the thickness direction of these p side contact layers can be lowered by forming p side contact layer thinly. It is still more preferred to set it as 300A or less in this invention. As for the minimum of the thickness of these p side contact layers, it is preferred to set it as not less than 10A so that the semiconductor layer under this p type contact layer may not be exposed.

[0018]moreover -- forming the 1st buffer layer on a substrate and forming on it the 2nd buffer layer that consists of a nitride semiconductor of 0.1 micrometers or more of thickness in this invention, -- this -- it is preferred to form n side contact layer which consists of a nitride semiconductor with which the n type impurity was doped on the 2nd buffer layer. By this, carrier concentration can form good large crystalline n side contact layer. In order to form said 2nd buffer layer with still more sufficient crystallinity, it is preferred that the impurity concentration of said 2nd buffer layer is low concentration as compared with said n side contact layer.

[0019]In this invention, as an impurity which determines a conductivity type, the [which is doped by the nitride semiconductor / periodic table] -- the [4A fellows, 4B fellows, and] -- the [6A fellows and] -- there are a n type impurity belonging to 6B fellows and a p type impurity belonging to 1A, 1B fellows, 2A fellows, and

2B fellows (this Description is hereafter described as a n type impurity and a p type impurity suitably.). As mentioned above, when bandgap energy differs in the 1st layer and 2nd layer, it is desirable to enlarge impurity concentration of a layer with larger bandgap energy. By this, a high increase in power by the abnormal-conditions dope at the time of forming superlattice layers in the p type nitride semiconductor layer side is expectable. In this invention, n side contact layers may be superlattice layers. Bandgap energy can differ mutually in two layers which constitute the superlattice layers which are n side contact layers, and power efficiency can be raised by enlarging impurity concentration of a layer with larger bandgap energy by an effect which was similar to HEMT mentioned later. For example, in a laser device, it is in threshold voltage and the tendency for a threshold current to fall, further.

[0020]

[Mode for carrying out the invention]Hereafter, the nitride semiconductor device of the embodiment which starts this invention with reference to Drawings is explained.

Embodiment 1. drawing 1 is the structure of the nitride semiconductor device of Embodiment 1 concerning this invention a shown typical sectional view, and this

nitride semiconductor device, As a fundamental structure, on the substrate 1 which consists of sapphire, The buffer layer 2 which consists of GaN(s), the n side contact layer 3 which consists of Si-dope n type GaN, the active layer 4 which consists of InGaN of single quantum well structure, the p side clad layer 5 which consists of superlattice layers by which the 1st layer that differs in a presentation mutually, and the 2nd layer were laminated, The p side contact layer 6 which consists of Mg dope GaN is the LED element laminated in order. In the nitride semiconductor device of Embodiment 1, all over almost [of the p side contact layer 6 surface], The whole surface electrode 7 of translucency is formed, the p electrode 8 for bonding is formed in the surface of the whole surface electrode 7, and the n electrode 9 is formed in the surface of the n side contact layer 2 further exposed from the p side contact layer 6 by carrying out etching removal of a part of nitride semiconductor layer.

[0021]The 1st layer of 30 A of thickness (A) which consists of $In_XGa_{1-X}N$ (0<=X<=1) in which the nitride semiconductor device of Embodiment 1 doped Mg, for example as a p type impurity here, Since it has the p side clad layer 5 which has the low resistance which comprised superlattice layers by which the 2nd layer of 30 A of thickness which consists of p type aluminum$_Y$$Ga_{1-Y}N$

(0<=Y<=1) which similarly doped Mg in the 1st layer and tales doses as a p type impurity was laminated, Vf can be made low. Thus, when forming superlattice layers in the p layer side, it is considered as the superlattice layers which dope p type impurities, such as Mg, Zn, Cd, and Be, in the 1st layer and/or the 2nd layer, and have a p type conductivity type. as laminating order -- the -- the [1+] -- the [2+the 1st ... or, and] -- the [2+] -- the order of 1+the 2nd ... may be sufficient, and at least a total of two or more layers are laminated.

[0022]The 1st layer and 2nd layer that consist of a nitride semiconductor which constitutes superlattice layers, It is not necessarily limited to the layer which consists of the layer and aluminum$_Y$Ga$_{1-Y}$N (0<=Y<=1) which consist of $In_XGa_{1-X}N$ (0<=X<=1), and what is necessary is just to comprise a nitride semiconductor with which presentations differ mutually. The bandgap energy of the 1st layer and the 2nd layer may differ, or it may be the same. For example, if the 1st layer is constituted from $In_XGa_{1-X}N$ (0<=X<=1) and the 2nd layer is constituted from aluminum$_Y$Ga$_{1-Y}$N (0< Y<=1), the bandgap energy of the 2nd layer will certainly become larger than the 1st layer, but. If the 1st layer is constituted from $In_XGa_{1-X}N$ (0<=X<=1) and the 2nd layer is constituted from $In_ZAl_{1-Z}N$ (0< Z<=1), bandgap energy may be the same although the 1st layer

and 2nd layer differ in a presentation. If the 1st layer is constituted from aluminum$_Y$Ga$_{1-Y}$N (0<=Y<=1) and the 2nd layer is constituted from In$_Z$Al$_{1-Z}$N (0< Z<=1), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation similarly. That is, as long as this invention is superlattice layers which have the operation mentioned later, its bandgap energy of the 1st layer and the 2nd layer may be the same, or they may differ. As mentioned above, since [which differs in a presentation] a film is laminated extremely and the thickness of each layer is thin enough, the superlattice layers said here are large concepts which say the thing of the layer laminated without the defect accompanying a stacking fault occurring, and include quantum well structure. Although these superlattice layers do not have a defect inside, since they have the distortion accompanying a stacking fault, they are also usually called a strained super lattice. In this invention, even if V group elements, such as As and P, replace a part of N (nitrogen) of the 1st layer and the 2nd layer, as long as N exists, it is contained in a nitride semiconductor.

[0023]In this invention, the thickness of the 1st layer and the 2nd layer which constitutes superlattice layers, Since the 1st layer and 2nd layer will serve as thickness beyond an elastic strain limit and a very small crack or a crystal defect

will enter easily into this film if thicker than 100 A, it is preferred to set it as thickness of 100 A or less. The minimum in particular of the thickness of the 1st layer and the 2nd layer is not limited, but should just be one or more atomic layers. However, in this invention the thickness of the 1st layer and the 2nd layer, The critical (elastic strain) marginal thickness of a nitride semiconductor is not fully reached as it is 100 A, It is most preferred for setting it as 70 A or less to set up desirable still more desirable more thinly, in order to use below elastic strain marginal thickness and to lessen the crystal defect of a nitride semiconductor more, and to set it as 40 A - 10 A. Although it may be set as 10 A or less (one atomic layer or two atomic layers) in this invention, if it is set as 10 A or less, For example, as for the thickness of the 1st layer and the 2nd layer, since formation time and time and effort are taken on ** more than which the number of laminations increases, and a manufacturing process when forming the cladding layer of thickness of 500 A or more by superlattice layers, it is preferred to set up more thickly than 10 A.

[0024]In the case of the nitride semiconductor device of this Embodiment 1 shown in drawing 1, the p type clad layer 5 which consists of superlattice layers is formed between the active layer 4 and the p side contact layer 6 which is

current injection layers, and is acting as a carrier confining layer. Thus, to make especially superlattice layers into a carrier confining layer, it is necessary to make average bandgap energy of superlattice layers larger than an active layer. In a nitride semiconductor, since the nitride semiconductor containing aluminum, such as AlN, AlGaN, and InAlN, has comparatively big bandgap energy, these layers are used as a carrier confining layer. However, if a thick film is grown up by an AlGaN single like before, it has the character in which a crack enters easily into crystal growth.

[0025]Then, the nitride semiconductor which contains aluminum at least in this invention for either [at least] the 1st layer of superlattice layers, or the 2nd layer, By forming aluminum$_{Y}$Ga$_{1-Y}$N (0< Y<=1) by the thickness below an elastic strain limit preferably, and constituting superlattice layers, growth formation of the good crystalline superlattice layers is carried out very much, and bandgap energy forms the layer big moreover with few cracks. In this case, it is made hard to act also as a buffer layer at the time of growing up the 2nd layer that consists of a nitride semiconductor containing aluminum, if the nitride semiconductor layer which does not contain aluminum in the 1st layer is grown up by thickness of 100 A or less still more preferably, and to go into the 2nd layer in a crack. Therefore,

even if it laminates the 1st layer and 2nd layer, good crystalline superlattice layers without a crack can be formed. Therefore, in this Embodiment 1, it is preferred to use superlattice layers as the 1st layer (the 2nd layer) that consists of $In_XGa_{1-X}N$ (0<=X<=1), and the 2nd layer (the 1st layer) that consists of aluminum$_Y$Ga$_{1-Y}$N (0<=Y<=1, X!=Y=0).

[0026]In the nitride semiconductor device of this Embodiment 1, in order to adjust carrier concentration to at least one layer of the 1st layer and the 2nd layer which constitute the p side clad layer 5 which is superlattice layers, it is preferred that the p type impurity which sets the conductivity type of this layer as a p type is doped. Dope ** is also good by the concentration in which the 1st layer differs from the 2nd layer when doping a p type impurity in the 1st layer and 2nd layer, and when the bandgap energy of the 1st layer and the 2nd layer differs, it is still more desirable for bandgap energy to make the big layer high concentration. It is because the carrier concentration of one layer can become high substantially and the resistance of the whole superlattice layers can be reduced according to the quantum effect by abnormal-conditions doping, if an impurity is doped by concentration which is different in the 1st layer and the 2nd layer, respectively. Thus, in this invention, an impurity may be doped by different

concentration in both the 1st layer and the 2nd layer, respectively, and an impurity may be doped in the 2nd either one of 1st layer or layer.

[0027]The impurity concentration doped by the 1st layer and 2nd layer, Although this invention in particular is not limited to this, usually with a p type impurity $1x10^{16}/cm^3$ - $1x10^{22}/cm^3$, It is still more preferably desirable $1x10^{17}/cm^3$ - $1x10^{21}/cm^3$, and to adjust to the range of $1x10^{18}/cm^3$ - $2x10^{20}/cm^3$ most preferably. It is because it is in the tendency for the crystallinity of superlattice layers to worsen when more [if less than $1x10^{16}/cm^3$, the effect of reducing Vf and threshold voltage will be hard to be acquired, and] than $1x10^{22}/cm^3$. It is desirable to also adjust a n type impurity to the same range. The Reason is the same.

[0028]However, in this invention, the impurity which determines a conductivity type as the 1st layer and 2nd layer does not need to be doped by superlattice layers. The superlattice layers by which this impurity is not doped may be which layers between an active layer and a substrate, as long as they are n type nitride semiconductor layer fields, and on the other hand, as long as they are p type nitride semiconductor layer fields, they may be which layers between a carrier confining layer (optical confinement layer) and an active layer.

[0029]Since the 1st layer and the 2nd layer are made into the thickness below an

elastic strain limit, are laminated and the superlattice layers constituted as mentioned above form them, the lattice defect of a crystal can be reduced, and they can decrease a very small crack, and can improve crystallinity fast. As a result, without spoiling crystallinity not much, increase doped quantity of an impurity for it and by this. Since it can move without being able to make the carrier concentration of a n type nitride semiconductor layer and a p type nitride semiconductor layer increase, and scattering about these carriers according to a crystal defect, as compared with the nitride semiconductor of a p type or a n type which does not have a superstructure, single or more figures resistivity can be made low.

[0030]Therefore, in the nitride semiconductor device (LED element) of this Embodiment 1. Obtaining a low resistance nitride semiconductor layer conventionally forms the p type clad layer 5 by the side of difficult p layer (p type semiconductor layer field (field which consists of the p type clad layer 5 and the p type contact layer 6)) using superlattice layers, By making low the resistance of this p type clad layer 5, Vf can be made low. That is, compared with a n type nitride semiconductor, resistivity is usually high [a p type nitride semiconductor / a p type crystal is a semiconductor which is very hard to be obtained, and], even

if a p type nitride semiconductor is obtained double or more figures. Therefore, by forming p type superlattice layers in the p layer side, the p type layer which comprised superlattice layers can be extremely made into low resistance, and the fall of Vf appears notably. in order to obtain a p type crystal conventionally, annealing of the nitride semiconductor layer which doped the p type impurity is carried out as technology, and the technology which produces a p type nitride semiconductor is known by removing hydrogen (patent No. 2540791). However, although the p type nitride semiconductor was obtained, the resistivity has more than number omega and cm. Then, crystallinity becomes good by making this p type layer into p type superlattice layers, according to our examination, this p layer resistivity [single or more figures] can be made low as compared with the former, and the effect that Vf makes it fall shows up notably.

[0031]In this Embodiment 1, the 1st layer (the 2nd layer) is preferably set to $In_XGa_{1-X}N$ (0<=X<=1) as mentioned above, Since the superlattice layers which do not have a good crystalline crack by constituting the 2nd layer (the 1st layer) from $aluminum_YGa_{1-Y}N$ (0<=Y<=1, X!=Y=0) can be formed, an element life can be raised.

[0032]Next, we compare and explain the conventional example and this

invention which were indicated by publicly known document containing the Patent Gazette for which it applied before. First, we proposed JP,H8-228048,A previously as technology similar to this invention. This technology is technology which forms the multilayer film which becomes the outside of the n type clad layer which sandwiches an active layer, and/or the outside (that is, side which is separated from an active layer) of a p type clad layer from AlGaN, GaN, InGaN, etc. as a light reflection film of a laser beam. Since a multilayer film is formed as a light reflection film, and the thickness of that each layer is designed by lambda / 4n (n: the refractive index of a nitride semiconductor, lambda:wavelength), this technology is dramatically thick. Therefore, each thickness of a multilayer film is not the thickness below an elastic strain limit. The laser device of the structure which inserted the active layer into USP No. 5,146,465 by the mirror which consists of aluminum$_X$Ga$_{1-X}$N/aluminum$_Y$Ga$_{1-Y}$N is indicated. In order to make AlGaN/AlGaN act as a mirror like [this technology] last technology, thickness of each layer must be thickened. It is dramatically difficult to laminate a many layers hard semiconductor still like AlGaN without a crack.

[0033]On the other hand, each thickness of the 2nd layer is set to the 1st constitute superlattice layers from this embodiment (both are preferably set to

100 A or less and below critical thickness.), and it differs from said technology. An effect by a strained super lattice of a nitride semiconductor which constitutes superlattice layers from this invention is used, crystallinity is raised, and Vf is reduced.

[0034]A method of laminating AlN and GaN of a thin film to JP,5-110138,A and JP,H5-110139,A, and obtaining a crystal of $aluminum_{Y}Ga_{1-Y}N$ is indicated. In order to obtain a mix crystal of $aluminum_{Y}Ga_{1-Y}N$ of a predetermined mixed crystal ratio, this technology is technology which laminates AlN of tens of A thickness, and GaN, and differs from technology of this invention. And since it does not have an active layer which consists of InGaN(s), a crack goes into superlattice layers easily. A light emitting device of terrorism structure is indicated by JP,H6-21511,A and the No. 268257 [six to] gazette to double which has an active layer of multiple quantum well structure which laminated GaN, InGaN or InGaN, and InGaN. In this invention, it is the technology which makes layers other than an active layer multiple quantum well structure, and differs also from this technology.

[0035]Furthermore, with the element of this invention, when equipping an active layer with a nitride semiconductor like InGaN which contains indium at least, the

effect of superlattice shows up notably. Bandgap energy is small and the InGaN active layer is most suitable as an active layer of a nitride semiconductor device. Therefore, since an active layer, a bandgap energy difference, and refractive index difference can be enlarged if the superlattice layers which consist of $In_XGa_{1-X}N$ and aluminum$_YGa_{1-Y}N$ are formed as a layer which sandwiches an active layer, When these superlattice layers realize a laser device, it operates as a dramatically outstanding optical confinement layer (it applies to the nitride semiconductor device of Embodiment 2). Since InGaN is [the character of a crystal] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. Conversely, when a nitride semiconductor like AlGaN is made into an active layer, since the character of the crystal is hard, it is in the tendency for a crack to go into the whole crystal easily.

[0036]It is desirable to adjust still more preferably 500 A or less of thickness [300 A or less of] of p side contact layer to 200 A or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor

layer to 500 A or less -- further -- resistivity -- it seems to be low -- since ****** is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0037]As mentioned above, in the nitride semiconductor device of this Embodiment 1, as explained in full detail, since the 1st layer and 2nd layer constitute the p type clad layer 5 from laminated superlattice layers, this p type clad layer 5 is extremely made to low resistance, and Vf of this element can be made low.

[0038]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use p type superlattice layers not only for this but for the p side contact layer 6. That is, the p side contact layer 6 into which current (electron hole) is poured can also be made into the p type superlattice layers by which the 1st layer that consists of $In_XGa_{1-X}N$, and the 2nd layer that consists of aluminum$_YGa_{1-Y}N$ were laminated. When the p type contact layer 6 is made into superlattice layers and the bandgap energy of the 1st layer is smaller than the 2nd layer, It is preferred to consider it as the layer which bandgap energy makes the outermost surface the 1st layer that consists of small

$In_XGa_{1-X}N$, and contacts p electrode, contact resistance with p electrode becomes small, and desirable OMIKKU is obtained by this. This is because the direction of the 1st layer with small bandgap energy is in the tendency for the nitride semiconductor layer whose carrier concentration is higher than the 2nd layer to be easy to be obtained. When forming further an above-mentioned p side clad layer and p type nitride semiconductor layers other than p side contact layer in a p type nitride semiconductor layer field, superlattice layers may constitute this p type nitride semiconductor layer from this invention.

[0039]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use n type superlattice layers for the n side contact layer 3 of not only a p type nitride semiconductor layer field but a n type nitride semiconductor field. Thus, when making the n side contact layer 3 into superlattice layers, n type impurities, such as Si and germanium, can be doped in the 1st layer and/or 2nd layer, and superlattice layers which have a n type conductivity type can be formed as the n type contact layer 3 between the substrate 1 and the active layer 4, for example. In this case, it was checked that it is in a tendency for lateral resistance to fall if especially the n type contact layer 3 is made into superlattice layers which differ in impurity concentration, and for

threshold voltage and current to fall in LD.

[0040]This about a case where superlattice layers which doped many n type impurities are formed in a direction of a big layer of bandgap energy as a contact layer by the side of a n layer. An effect in which an operation similar to the following HEMT(s) (High-Electron-Mobility-Transistor) appeared is guessed. The 1st layer with a large band gap by which a n type impurity was doped (the 2nd layer), A band gap in superlattice layers which laminated the 2nd layer (the 1st layer) of small undoping {(undope) the state where an impurity is not doped below as for; is called undoping}. By a heterojunction interface of a layer which added a n type impurity, and a undoped layer, the big layer side of bandgap energy depletion-izes, and an electron (two dimensional electron gas) is accumulated in an interface before and behind thickness (100 A) by the side of a small layer of bandgap energy. In order not to receive dispersion by an impurity when an electron runs since this two dimensional electron gas turns on a small layer side of bandgap energy, the degree of electron transfer of superlattice layers becomes high, and is guessed that resistivity falls.

[0041]In this invention, when providing the cladding layer by the side of n in a n type nitride semiconductor layer field, it is good also considering the cladding

layer by the side of this n as superlattice layers. When forming n type nitride semiconductor layers other than n side contact layer and a n side clad layer in a n type nitride semiconductor layer field, it is good also considering this n type nitride semiconductor layer as superlattice layers. However, when providing the nitride semiconductor layer which consists of superlattice layers in a n type nitride semiconductor layer field, it cannot be overemphasized that it is desirable to make into a superstructure the n side clad layer as a carrier confining layer or the n side contact layer 3 into which current (electron) is poured.

[0042]thus, when looking superlattice layers like [the n type nitride semiconductor layer field between the active layer 4 and the substrate 1] and providing them, it is not necessary to dope an impurity in the 1st layer and the 2nd layer which constitute superlattice layers It is because there is character which becomes a n type even when a nitride semiconductor is undoped. However, it is more desirable to dope n type impurities, such as Si and germanium, in the 1st layer and the 2nd layer, and to establish the difference of impurity concentration as mentioned above, when forming in the n layer side.

[0043]As mentioned above, crystalline improvement is mentioned like the case where the effect at the time of forming superlattice layers in a n type nitride

semiconductor layer field provides superlattice layers in a p type nitride semiconductor layer field. When it explains in detail, in the case of the nitride semiconductor device which has a hetero-junction, the carrier confining layer of a n type and a p type usually comprises AlGaN with larger bandgap energy than an active layer. Crystal growth is dramatically difficult for AlGaN, for example, when you are going to make it grow up by thickness of 0.5 micrometers or more with single composition, there is character in which a crack enters easily during a crystal. However, since a good crystalline thing will be obtained only in the 1st single layer and the 2nd layer if the 1st layer and the 2nd layer are laminated by the thickness below an elastic strain limit like this invention and it is superlattice layers, while crystallinity has been good also as thick superlattice layers of thickness, a cladding layer can grow the whole. Therefore, since the crystallinity of the whole nitride semiconductor becomes good and the mobility of a n type region becomes large, Vf falls with the element which made the superlattice layers the cladding layer. It seems that an effect similar to the above mentioned HEMT comes to show up notably when the impurity of Si and germanium is doped to superlattice layers and superlattice layers are made into a contact layer, and threshold voltage and Vf can be reduced further.

[0044]Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0045]Embodiment 2 concerning embodiment 2., next this invention is described. Drawing 2 is the structure of the nitride semiconductor device of Embodiment 2 concerning this invention a shown typical sectional view (section vertical to the resonant direction of a laser beam), and this nitride semiconductor device, For example, on the substrates 10, such as sapphire which makes C side a principal surface, A n type nitride semiconductor layer field. (it consists of the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15.) -- by a p type nitride semiconductor field (it consists of the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20.). It is the nitride semiconductor laser diode element provided with the active layer 16 which consists of a sandwiched nitride semiconductor.

[0046]Here the nitride semiconductor device of this Embodiment 2, The threshold voltage of the nitride semiconductor device which is an LD element is low set up by forming the n side clad layer 14 in a n type nitride semiconductor layer field by superlattice layers, and forming the p side clad layer 19 in a p type nitride semiconductor field by superlattice layers. The nitride semiconductor device of Embodiment 2 which starts this invention with reference to this drawing 2 below is explained in detail.

[0047]In the nitride semiconductor device of this Embodiment 2, First, the n side contact layer 12 is formed via the buffer layer 11 and the 2nd buffer layer 112 on the substrate 10, further, on the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15 are laminated, and a n type nitride semiconductor layer field is formed. The n lateral electrode 23 which carries out ohmic contact to the n side contact layer 12 is formed in the surface of the n side contact layer 12 exposed to the both sides of the crack prevention layer 13, respectively, and the n side pad electrode for wire bonding is formed on these n lateral electrodes 23, for example. And the active layer 16 which consists of nitride semiconductors is formed on the n side light guide layer 15, further, on this active layer 16, the cap layer 17, the p side light

guide layer 18, the p side clad layer 19, and the p side contact layer 20 are laminated, and a p type nitride semiconductor layer field is formed. The p lateral electrode 21 which carries out ohmic contact to these p side contact layers 20 is formed on the p side contact layer 20, and p side pad electrode for wire bonding is formed on these p lateral electrodes 21, for example. By the upper part of the p side contact layer 20 and the p side clad layer 19. By the ridge part of the shape of Mine extended for a long time being constituted by the resonant direction, and forming this ridge part in it, In the active layer 16, light is shut up crosswise (direction which intersects perpendicularly with a resonant direction), and laser oscillation of the resonator which resonates to the longitudinal direction of a ridge part is produced and carried out using the cleavage plane by which cleavage was carried out in the direction vertical to a ridge part (electrode of stripe shape).

[0048]Next, each component of the nitride semiconductor device of Embodiment 2 is explained.

(Substrate 10) R side besides the sapphire which makes C side the substrate 10 with a principal surface, Semiconductor substrates, such as SiC (6H, 4H, and 3C are included), ZnS, ZnO, GaAs, GaN, etc. besides the sapphire which makes A

side a principal surface, and other insulating substrates like a spinel (MgA1 $_2O_4$), can be used.

[0049](Buffer layer 11) The buffer layer 11 grows up AlN, GaN, AlGaN, InGaN, etc. at the temperature of 900 ** or less, for example, and is formed in a thickness number (10 A - hundreds of A). In order that this buffer layer 11 may ease the grating constant injustice of a substrate and a nitride semiconductor, it forms, but it is also possible to omit according to the growing method of a nitride semiconductor, the kind of substrate, etc.

[0050](The 2nd buffer layer 112) On said buffer layer 11, the 2nd buffer layer 112 is a layer which consists of a nitride semiconductor of the single crystal grown up at the elevated temperature rather than said buffer layer, and has a thick film rather than the buffer layer 11. the nitride semiconductor layer which this 2nd buffer layer 112 considers it as a layer with less n type impurity concentration than the n side contact layer 12 grown up into the next, or does not dope a n type impurity -- if it is a GaN layer preferably, the crystallinity of the 2nd buffer layer 112 will become good. If a n type impurity is most preferably set to undoped GaN, a nitride semiconductor with the most sufficient crystallinity will be obtained. If not less than several micrometers thickness tends to constitute n

side contact layer which forms the negative electrode like before from the single nitride semiconductor layer of high carrier concentration, it is necessary to grow up a layer with large n type impurity concentration. As for the layer of a thick film with large impurity concentration, crystallinity tends to worsen. For this reason, on a bad crystalline layer, even if it grows up other nitride semiconductors, such as an active layer, other layers will succeed a crystal defect and crystalline improvement cannot be expected. Then, before growing up 12 layers of n side contact layers, carrier concentration can grow up the good large crystalline n side contact layer 12 by growing up the 2nd good crystalline buffer layer 112 with small impurity concentration. As for the thickness of this 2nd buffer layer 112, it is still more preferably desirable most preferably to adjust to 1 micrometers or more and 20 micrometers or less 0.5 micrometers or more 0.1 micrometers or more. When the 2nd buffer layer 112 is thinner than 0.1 micrometer, the n type contact layer 12 with large impurity concentration must be grown up thickly, and it is in the tendency which can seldom expect crystalline improvement in the n side contact layer 12. When thicker than 20 micrometers, it is in the tendency for a crystal defect to increase easily in the 2nd buffer layer 112 the very thing. It is considered as the advantage into which the 2nd buffer layer 112 is grown up

thickly, and improvement in heat dissipation nature is mentioned. That is, when a laser device is produced, the life of a laser device improves that heat spreads easily in the 2nd buffer layer 112. Furthermore, the light leaking of a laser beam spreads within the 2nd buffer layer 112, and it becomes easy to obtain the laser beam near an ellipse form. The 2nd buffer layer 112 may be omitted when conductive substrates, such as GaN, SiC, and ZnO, are used for a substrate.

[0051](n side contact layer 12) The n side contact layer 12 is a layer which acts as a contact layer which forms the negative electrode, and it is desirable to adjust to 0.2 micrometers or more and 4 micrometers or less. If thinner than 0.2, when forming the negative electrode later, it is difficult to control an etching rate so that this layer may be exposed, and when not less than 4 micrometers is used, on the other hand, it is in the tendency for crystallinity to worsen under the influence of an impurity. The range of the n type impurity doped to the nitride semiconductor of this n side contact layer 12 The range of $1x10^{17}/cm^3$ - $1x10^{21}/cm^3$, It is desirable to adjust to $1x10^{18}/cm^3$ - $1x10^{19}/cm^3$ still more preferably. Since the material of n electrode and desirable OMIKKU will become is hard to be obtained if smaller than $1x10^{17}/cm^3$, In a laser device, a fall of a threshold current and voltage cannot be expected, but since the leakage current of the

element itself will increase and crystallinity will also worsen if larger than $1x10^{21}/cm^3$, it is in the tendency for the life of an element to become short. In the n side contact layer 12, in order to make small ohmic contact resistance with the n electrode 23, it is desirable to make larger than the n cladding layer 14 concentration of the impurity which raises the carrier concentration of these n side contact layers 12. The n side contact layer 12 acts not as a contact layer but as a buffer layer, when providing the negative electrode in a substrate at the substrate rear side using conductive substrates, such as GaN, SiC, and ZnO.

[0052]At least one layer of the 2nd buffer layer 11 and the n side contact layers 12 can also be made into superlattice layers. If it is superlattice layers, the crystallinity of this layer will become good by leaps and bounds, and a threshold current will fall. Let the desirable n side contact layer 12 in which thickness is thinner than the 2nd buffer layer 11 be superlattice layers. In the case where the n side contact layer 12 is made into the superstructure which comes to laminate the 1st layer that differs in bandgap energy mutually, and the 2nd layer, By exposing the desirable small layer of bandgap energy and forming the n electrode 23, contact resistance with the n electrode 23 can be made low, and can reduce a threshold value. As a n type nitride semiconductor and a material

of the n electrode 23 in which desirable OMIKKU is obtained, metal or alloys, such as aluminum, Ti, W, Si, Zn, Sn, and In, are mentioned.

[0053]By making the n type contact layer 12 into the superlattice layers which differ in impurity concentration, lateral resistance can be made low by an effect similar to HEMT explained in Embodiment 1, and the threshold voltage of an LD element and current can be made low.

[0054](Crack prevention layer 13) The crack prevention layer 13 consists of $In_{0.1}Ga_{0.9}N$ which cm-^{3}[5x10 ^{18}/]-doped Si, for example, and has 500-A thickness, for example. This crack prevention layer 13 can prevent a crack from entering into the nitride semiconductor layer containing aluminum formed on it the n type nitride semiconductor containing In and by growing up InGaN preferably and forming. As for this crack prevention layer 13, it is preferred to make it grow up by 100 A or more and 0.5 micrometer or less of thickness. If thinner than 100 A, it will be hard to act as crack prevention as mentioned above, and when thicker than 0.5 micrometer, it is in the tendency for the crystal itself to be discolored in black. This crack prevention layer 13 may be omitted, when using the n side contact layer 12 as superlattice like this Embodiment 1, or when making into superlattice layers the n side clad layer 14 grown up into the next.

[0055](N side clad layer 14 which consists of n type superlattice) A n side clad layer, For example, it consists of n typeA10.2Ga0.8N which cm-^{3}[5x10 ^{18}/]-doped Si, The 1st layer that has 20-A thickness, and the 2nd layer that consists of undoped GaN and has 20-A thickness consist of superlattice layers laminated by turns, and it has 0.5 micrometer of thickness on the whole. This n type clad layer 14 acts as a carrier confining layer and an optical confinement layer, The nitride semiconductor which contains aluminum for one of layers when it is considered as superlattice layers, It is desirable to grow up AlGaN preferably and 2 micrometers or less of 100 A or more can grow a good carrier confining layer by making it grow up at 500 A or more and 1 micrometer or less still more preferably. Although this n type clad layer 14 can also be grown up with a single nitride semiconductor, the good crystalline carrier confining layer where a crack does not have considering it as superlattice layers can be formed.

[0056](n side light guide layer 15) The n side light guide layer 15 consists of n type GaN which cm-^{3}[5x10 ^{18}/]-doped Si, for example, and has 0.1 micrometer of thickness. As for this n side light guide layer 6, it is desirable to act as a light guide layer of an active layer, to grow up GaN and InGaN, and to form, and it is usually desirable to make it grow up by 200 A - 1 micrometer of thickness still

more preferably 100 A - 5 micrometers. This light guide layer 15 can also be made into superlattice layers. When making the n side light guide layer 15 and the n side clad layer 14 into superlattice layers, average bandgap energy of the nitride semiconductor layer which constitutes superlattice layers is made larger than an active layer. When considering it as superlattice layers, a n type impurity may be doped in either [at least] the 1st layer or the 2nd layer, and undoping may be sufficient. The superlattice by which a undoped nitride semiconductor independent or a undoped nitride semiconductor was laminated may be sufficient as this light guide layer 15.

[0057](Active layer 16) The well layer which the active layer 16 consists of $In_{0.2}Ga_{0.8}N$ which doped Si by 8x10 $^{18}/cm^3$, for example, and has 25-A thickness, It consists of $In_{0.05}1Ga_{0.95}N$ which cm-^{3}[8x10 ^{18}/]-doped Si, and constitutes from multiple quantum well structure (MQW) which has predetermined thickness by laminating by turns the barrier layer which has 50-A thickness. In the active layer 16, an impurity may be doped to both a well layer and a barrier layer, and it may dope to either. When a n type impurity is doped, it is in the tendency for a threshold value to fall. Superlattice layers are distinguished in order to certainly laminate the small well layer of bandgap energy, and the barrier layer in which

bandgap energy is smaller than a well layer, in making the active layer 16 into multiple quantum well structure in this way. 100 A or less of thickness [70 A or less of] of a well layer shall be 50 A or less most preferably. 150 A or less of thickness [100 A or less of] of a barrier layer shall be 70 A or less most preferably.

[0058](p side cap layer 17) Rather than the active layer 16, bandgap energy is large, for example, consists of p type aluminum$_{0.3}$Ga$_{0.7}$N which cm-^{3}[1x10 ^{20}/]-doped Mg, and the p side cap layer 17 has 200-A thickness, for example. Although it is preferred in this Embodiment 2 to use the cap layer 17 in this way, since this cap layer is formed in thin thickness, it is good also as an i type which doped the n type impurity and with which the carrier was compensated by this invention. 0.1 micrometer or less of thickness [500 A or less of] of the p side cap layer 17 is most preferably adjusted to 300 A or less still more preferably. It is because a crack enters easily into the p side cap layer 17 and a good crystalline nitride semiconductor layer cannot grow easily, if it is made to grow up by thickness thicker than 0.1 micrometer. It is because it becomes impossible to pass the p type capping layer 17 from which a carrier becomes that the thickness of the p side cap layer 17 is 0.1 micrometers or more with this energy

barrier according to the tunnel effect, When passage of the carrier by this tunnel effect is taken into consideration, it is preferred to set it as 500 A or less and 300 more A or less to have mentioned above.

[0059]To the p side cap layer 17, in order to make an LD element easy to oscillate, it is preferred that the composition ratio of aluminum uses and forms large AlGaN, and it becomes easy to oscillate an LD element, so that this AlGaN is formed thinly. For example, if Y value is 0.2 or more aluminum$_{Y}$Ga$_{1-Y}$N, adjusting to 500 A or less is desirable. Although the minimum in particular of the thickness of the p side cap layer 17 does not limit, it is desirable to form by thickness of 10 A or more.

[0060](p side light guide layer 18) Bandgap energy is smaller than the p side cap layer 17, for example, consists of p type GaN which cm^{-3}[1x10 ^{20}/]-doped Mg, and the p side light guide layer 18 has 0.1 micrometer of thickness. As for this p side light guide layer 18, it is desirable to act as a light guide layer of the active layer 16, to make it grow up by GaN and InGaN as well as the n side light guide layer 15, and to form. This layer acts as a desirable light guide layer by acting also as a buffer layer at the time of growing up the p side clad layer 19, and growing up 100 A - 5 micrometers by 200 A - 1 micrometer of thickness still more

preferably. Although this p side light guide layer usually dopes p type impurities, such as Mg, and considers it as a p type conductivity type, it is not necessary to dope an impurity in particular. This p side light guide layer can also be made into superlattice layers. When considering it as superlattice layers, a p type impurity may be doped in either [at least] the 1st layer or the 2nd layer, and undoping may be sufficient.

[0061](P side clad layer 19= superlattice layers) The p side clad layer 19, For example, the 1st layer that consists of p type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg, and has 20-A thickness, for example, For example, it consists of p type GaN which cm^{-3}[1x10 ^{20}/]-doped Mg, and the 2nd layer that has 20-A thickness consists of superlattice layers laminated by turns. This p side clad layer 19 acts as a carrier confining layer as well as the n side clad layer 14, and acts as a layer for reducing especially the resistivity of a p type layer. Although the thickness in particular of this p side clad layer 19 is not limited, either, it is desirable to form at 500 A or more and 1 micrometer or less still more preferably 2 micrometers or less 100 A or more.

[0062](p side contact layer 20) On the p side clad layer 19, the p side contact layer 20 consists of p type GaN which cm^{-3}[2x10 ^{20}/]-doped Mg, for example,

and has 150-A thickness, for example. This p side contact layer 20 can be constituted from p type $In_XAl_YGa_{1-X-Y}N$ (0<=X, 0<=Y, X+Y<=1), and if referred to as GaN which doped Mg as mentioned above preferably, the p electrode 21 and the most desirable ohmic contact will be obtained. It is desirable to adjust still more preferably 500 A or less of thickness [300 A or less of] of p side contact layer to 200 A or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor layer to 500 A or less -- further -- resistivity -- it seems to be low -- since ****** is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0063]The p side contact layer 20 can also be made into superlattice layers in this invention. Especially in considering it as superlattice layers, it laminates the 1st layer and 2nd layer that differ in bandgap energy, the -- the [1+] -- the [2+] -- 1+ the 2+ ... as -- if it laminates and is finally made exposed [a layer with smaller bandgap energy], the p electrode 21 and desirable ohmic contact will be obtained. As a material of the p electrode 21, nickel, Pd, nickel/Au, etc. can be mentioned, for example.

[0064]The insulator layer 25 which consists of SiO_2 is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23 in this Embodiment 2 as shown in drawing 2, The p pad electrode 22 electrically connected with the p electrode 21 via an opening formed in this insulator layer 25 and the n pad electrode 24 connected with the n electrode 23 are formed. this p pad electrode 22 extends surface area of the substantial p electrode 21 -- the p electrode side -- wire bonding -- being able to be made to carry out die bonding, on the other hand, the n pad electrode 24 prevents peeling of the n electrode 23.

[0065]The nitride semiconductor device of above Embodiment 2 is provided with the good crystalline p type clad layer 19 which is the superlattice layers which made the 1st layer and the 2nd layer the thickness below an elastic strain limit, and were laminated. By this, since the nitride semiconductor device of this Embodiment 2 can make low the single or more figures resistance of the p side clad layer 19 as compared with the p side clad layer which does not have a superstructure, it can make threshold voltage and current low.

[0066]The p side clad layer 19 which contains p type $aluminum_YGa_{1-Y}N$ in the nitride semiconductor device of this Embodiment 2 is touched, By forming the

thickness thinly with 500 A or less by making the small nitride semiconductor of bandgap energy into the p side contact layer 20, The carrier concentration of the p side contact layer 20 becomes high substantially, p electrode and desirable OMIKKU are obtained, and the threshold current of an element and voltage can be made low. Since it has the 2nd buffer layer 112 before growing up n side contact layer, the crystallinity of the nitride semiconductor layer grown up on the 2nd buffer layer 112 becomes good, and a long lasting element can be realized. If n side contact layer grown up on the 2nd buffer layer 112 is preferably used as superlattice, lateral resistance becomes low and the low element of threshold voltage and a threshold current can be realized.

[0067]In equipping the active layer 16 with a nitride semiconductor like InGaN which contains indium at least in the LD element of this Embodiment 2, It is preferred that $In_XGa_{1-X}N$ and $aluminum_YGa_{1-Y}N$ use the superlattice layers laminated by turns as a layer (the n side clad layer 14 and the p side clad layer 19) which sandwiches the active layer 16. By this, since the bandgap energy difference of the active layer 16 and these superlattice layers and refractive index difference can be enlarged, these superlattice layers can be operated as a dramatically outstanding optical confinement layer, when realizing a laser device.

Since InGaN is [the character of a crystal] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. The life of an LD element can be lengthened by this.

[0068]In the case of the semiconductor device of the double hetero structure of having the active layer 16 which has quantum well structure like this Embodiment 2, the active layer 16 is touched, The p side cap layer 17 which consists of a nitride semiconductor of 0.1 micrometer or less of thickness with larger bandgap energy than the active layer 16, and the p side cap layer 17 which consists of a nitride semiconductor which contains aluminum preferably are formed, The p side light guide layer 18 in which bandgap energy is smaller than the p side cap layer 17 is formed in the position which is separated from an active layer rather than the p side cap layer 17, It is dramatically more preferred than the p side light guide layer 18 to form the p side clad layer 19 which has a superstructure which contains a nitride semiconductor with a larger band gap than the p side light guide layer 18 and the nitride semiconductor which contains aluminum preferably in the position which is separated from an active layer. And

in order that the electron poured in from the n layer since bandgap energy of the p side cap layer 17 was enlarged may be prevented by this p side cap layer 17, and may be shut up and an electron may not overflow an active layer, the leakage current of an element decreases.

[0069]Although the nitride semiconductor device of above Embodiment 2 showed a structure desirable as a structure of a laser device, What is necessary is just to have at least one layer of n type superlattice layers from the active layer 16 in this invention to the lower n type nitride semiconductor layer field (n type layer side), What is necessary is just to also have at least one layer of p type superlattice layers from the active layer 16 to the upper p type nitride semiconductor layer field (p type layer side), and element composition in particular is not specified. However, said superlattice layers are formed in the p side clad layer 19 as a carrier confining layer when forming in the p layer side, When forming in the n layer side and forming as the n contact layer 12 as a current injection layer which the n electrode 23 touched, or the n cladding layer 14 as carrier ****** reduces Vf of an element, and a threshold value, it is in the most desirable tendency. It cannot be overemphasized that the same composition as the element of Embodiment 2 is applicable to a LED element

(however, in a LED element, a ridge part is unnecessary).

[0070]In the nitride semiconductor device of Embodiment 2 constituted as mentioned above. In the atmosphere which does not contain H, for example, a nitrogen atmosphere, after each layer is formed, It is preferred to perform annealing, for example at 700 ** not less than 400 **, and since each layer of a p type nitride semiconductor layer field can be further low-resistance-ized by this, threshold voltage can be further made low by this.

[0071]In a nitride semiconductor device of Embodiment 2, the p electrode 21 which becomes the surface of the p side contact layer 12 from nickel and Au was formed in stripe shape, n side contact layer was symmetrically exposed to this p electrode 21, and the n electrode 23 is formed all over almost [of that n side contact layer surface]. Thus, when structure of forming the n electrode 23 symmetrically with both sides of the p electrode 21 when an insulating substrate is used makes threshold voltage low, it is dramatically advantageous.

[0072]In this Embodiment 2, a dielectric multilayer which consists of SiO_2 and TiO_2 may be formed in a cleavage plane (resonator face) which carried out cleavage in a direction vertical to a ridge part (electrode of stripe shape).

[0073]Thus, a cladding layer as a carrier confining layer formed in a n type

region or a p type region where superlattice layers sandwich an active layer in this invention, Since it is used as a light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that average bandgap energy of a nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0074]

[Working example]Hereafter, in working example, this invention is explained in full detail.

[Working example 1] Working example 1 concerning this invention is an example of creation of a nitride semiconductor device (LD element) shown in drawing 2, and is produced in the following procedures. First, passing hydrogen, after setting the substrate 10 which consists of sapphire (C side) in a reaction vessel and replacing inside of a container enough from hydrogen, temperature of a substrate is raised to 1050 ** and a substrate is cleaned. Then, temperature is lowered to 510 **, hydrogen is used for carrier gas, ammonia (NH_3) and TMG (trimethylgallium) are used for material gas, and the 1st buffer layer 11 that comes from GaN on the substrate 10 is grown up by about 200-A thickness.

[0075]Only TMG is stopped after buffer layer 11 growth, and temperature is

raised to 1050 **. If it becomes 1050 **, similarly TMG and ammonia gas will be used for material gas, and the 2nd buffer layer 112 that consists of the undoping GaN of carrier concentration 1x10 ^{18}/cm^{3} will be grown up by 5-micrometer thickness. the 2nd buffer layer -- $In_XAl_YGa_{1-X-Y}N$ (0<=X.) Although it can constitute from 0<=Y and X+Y<=1 and the presentation in particular is not asked, it is preferably undoped and aluminum (Y value) sets to 0.1 or less aluminum$_Y$Ga$_{1-Y}$N and most desirable undoped GaN. Then, silane gas (SiH_4) is used for TMG, ammonia, and impurity gas at 1050 **, and the n side contact layer 12 which consists of n type GaN which cm-^{3}[1x10 ^{19}/]-doped Si is grown up by 1 micrometer of thickness. When this n side contact layer 12 is formed by superlattice, it is still more preferred.

[0076]Temperature shall be 800 ** and to material gas Next, TMG, TMI (trimethylindium), Silane gas is used for ammonia and impurity gas, and the crack prevention layer 13 which consists of $In_{0.1}Ga_{0.9}N$ which cm--^{3}[5x10 ^{18}/]-doped Si is grown up by 500-A thickness. And temperature shall be 1050 ** and TMA, TMG, ammonia, and silane gas are used, The 1st layer that consists of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[5x10 ^{18}/]-doped Si is grown up by 20-A thickness, then TMA and Silang are stopped and the 2nd layer that consists of

the undoping GaN is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the n side clad layer 14 which consists of superlattice layers of 0.4 micrometer of the total thickness is grown up.

[0077]Then, the n side light guide layer 15 which consists of n type GaN which cm^{-3}[$5x10^{18}$/]-doped Si at 1050 ** is grown up by 0.1 micrometer of thickness. Next, the active layer 16 is grown up using TMG, TMI, ammonia, and Silang. The active layer 16 holds temperature at 800 **, and grows up the well layer which consists of $In_{0.2}Ga_{0.8}N$ which doped Si by $8x10^{18}/cm^3$ first by 25-A thickness. Next, the barrier layer which consists of $In_{0.01}Ga_{0.99}N$ which cm^{-3}[$8x10^{18}$/]-doped Si at the same temperature only by changing the mole ratio of TMI is grown up by 50-A thickness. This operation is repeated twice and the active layer 16 of the multiple quantum well structure (MQW) of 175 A of the total thickness that finally laminated the well layer is grown up.

[0078]Raise temperature to 1050 ** and to material gas Next, TMG, TMA, ammonia, Cp_2Mg (magnesium cyclopentadienyl) is used for impurity gas, The p side cap layer 17 which consists of p type $aluminum_{0.3}Ga_{0.7}N$ in which bandgap energy was large and cm^{-3}[$1x10^{20}$/]-doped Mg rather than the active layer is grown up by 300-A thickness. Then, the p side light guide layer 18 which

bandgap energy becomes at 1050 ** from p type GaN smaller than the p side cap layer 17 to which Mg was cm-^{3}[1x10 ^{20}/]-doped is grown up by 0.1 micrometer of thickness.

[0079]Then, TMA, TMG, ammonia, and Cp_2Mg are used, The 1st layer that consists of p type $aluminum_{0.2}Ga_{0.8}N$ which cm-^{3}[1x10 ^{20}/]-doped Mg at 1050 ** is grown up by 20-A thickness, Then, only TMA is stopped and the 2nd layer that consists of p type GaN which cm-^{3}[1x10 ^{20}/]-doped Mg is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness is formed. The p side contact layer 20 which finally consists of p type GaN which cm--^{3}[2x10 ^{20}/]-doped Mg on the p side clad layer 19 at 1050 ** is grown up by 150-A thickness.

[0080]Temperature is lowered to a room temperature after ending reaction, among a nitrogen atmosphere, in a reaction vessel for a wafer, annealing is performed at 700 ** and a p type layer is low-resistance-ized further. As a wafer is picked out from a reaction vessel after annealing and it is shown in drawing 2, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has

the stripe width of 4 micrometers.

[0081]Next, as a mask is formed in the ridge surface and it is shown in drawing 2, it is made symmetrical to a ridge of stripe shape, and the surface of the n side contact layer 12 is exposed. Next, the p electrode 21 which consists of nickel and Au all over almost [of the stripe ridge outermost surface of the p side contact layer 20] is formed. On the other hand, the n electrode 23 which consists of Ti and aluminum is formed all over almost [of the n side contact layer 3 of stripe shape].

[0082]Next, as shown in drawing 2, the insulator layer 25 which consists of SiO_2 is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23, and the p pad electrode 22 electrically connected with the p electrode 21 via this insulator layer 25 and the n pad electrode 24 are formed. A wafer which formed n electrode and p electrode as mentioned above shall be transported to polish equipment, the silicon on sapphire 1 of a side which does not form a nitride semiconductor shall be wrapped using a diamond polishing agent, and thickness of a substrate shall be 50 micrometers. After wrapping, 1 micrometer is polished with still finer abrasive soap, and a substrate face is made into mirror finished surface form.

[0083]The scribe after substrate polish and of the polished surface side is carried out, cleavage is carried out to bar shape in a direction vertical to the electrode of stripe shape, and a resonator is produced to a cleavage plane. The dielectric multilayer which consists of SiO_2 and TiO_2 was formed in the resonator face, and finally, in the direction parallel to p electrode, the bar was cut and it was considered as the laser chip. Next, in [when the chip was installed in the heat sink by face up (state which the substrate and the heat sink countered), wire bonding of each electrode was carried out and laser oscillation was tried at the room temperature] a room temperature, With threshold current density 2.9 kA/cm^2 and the threshold voltage 4.4V, continuous oscillation with an oscillation wavelength of 405 nm was checked, and the life of 50 hours or more was shown.

[0084](Comparative example 1) n type GaN which did not grow up the 2nd buffer layer 112 and cm^{-3}[1x10 ^{19}/]-doped Si for the n side contact layer 12 further on the other hand -- it being single, and 5 micrometers being grown up, and, 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum$_{0.2}$Ga$_{0.8}$N single which cm^{-3}[1x10 ^{19}/]-doped Si, 0.4 micrometer of p side clad layers 19 are grown up by the p type aluminum$_{0.2}$Ga$_{0.8}$N single which 1-x-10-^{20}-/-m-^{3}-doped Mg, 0.2 micrometer of single p type GaN(s) which

furthermore cm^{-3}[2x10 ^{20}/]-doped Mg for the p side contact layer 20 were grown up, and also the laser device was obtained like working example 1. That is, as basic constitution, as shown in Table 1, it constitutes.

[0085]

[Table 1]

基板	１０・・・サファイア	
ﾊﾞｯﾌｧ層	１１・・・ＧａＮ	２００Å
nｺﾝﾀｸﾄ層	１２・・・Ｓｉドープｎ型ＧａＮ Si:１×１０^{19}／cm^3	５μm
ｸﾗｯｸ防止層	１３・・・Ｓｉドープｎ型Ｉｎ0.1Ｇａ0.9N Si:５×１０^{18}／cm^3	５００Å
nｸﾗｯﾄﾞ層	１４・・・Ｓｉドープｎ型Ａｌ0.2Ｇａ0.8N Si:５×１０^{18}／cm^3	０．５μm
n光ｶﾞｲﾄﾞ層	１５・・・Ｓｉドープｎ型ＧａＮ Si:５×１０^{18}／cm^3	０．１μm
活性層(MQW) （総膜厚１７５Å）	１６・・・ＳｉドープＩｎ0.2Ｇａ0.8N ＳｉドープＩｎ0.01Ｇａ0.95N Si:８×１０^{18}／cm^3	２５Å ５０Å
ｷｬｯﾌﾟ層	１７・・・ＭｇドープｐＡｌ0.1Ｇａ0.9N Mg:１×１０^{20}／cm^3	３００Å
p光ｶﾞｲﾄﾞ層	１８・・・Ｍｇドープｐ型ＧａＮ Mg:１×１０^{20}／cm^3	０．１μm
pｸﾗｯﾄﾞ層	１９・・・Ｍｇドープｐ型Ａｌ0.2Ｇａ0.8N Mg:１×１０^{20}／cm^3	０．５μm
pｺﾝﾀｸﾄ層	２０・・・Ｍｇドープｐ型ＧａＮ Mg:２×１０^{20}／cm^3	０．２μm

[0086]Although continuous oscillation was checked by threshold current density 7 kA/cm^2 as for the laser device of the comparative example constituted in this way, threshold voltage has gone out in those or more [8.0] with V, and several minutes.

[0087][Working example 2] The 1st layer that consists the n side contact layer 12 of n type $aluminum_{0.05}Ga_{0.95}N$ which cm^{-3}[2x10 ^{19}/]-doped Si in working example 1 is grown up by 30-A thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 30-A thickness, this is repeated, and it is considered as the superstructure of 1.2 micrometers of the total thickness. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 2.7 kA/cm^2 and the threshold voltage 4.2V, and, as for the other structure, the life also showed 60 hours or more.

[0088][Working example 3] In working example 2, set the 2nd layer to GaN which cm^{-3}[1x10 ^{18}/]-doped Si in the superlattice which constitutes the n side contact layer 12, and also. When the laser device which has the same structure as working example 2 was produced, the laser device which has the characteristic almost equivalent to working example 2 was obtained.

[0089][Working example 4] In working example 1, set the 2nd buffer layer 112 to GaN which cm^{-3}[1x10 ^{17}/]-doped Si, and grow up it 4 micrometers, and also. When the laser device which has the same structure as working example 1 was produced, it went up to threshold current density 2.9 kA/cm^2 and the threshold voltage 4.5V, but the life showed 50 hours or more.

[0090][Working example 5] The 1st layer that consists the n side contact layer 12 of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[2x10 ^{19}/]-doped Si in working example 1 is grown up by 60-A thickness, Then, the 2nd layer that consists of GaN which cm-^{3}[1x10 ^{19}/]-doped Si is grown up by 40-A thickness, this is repeated successively, and it is considered as the superstructure of 2 micrometers of the total thickness. And 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum$_{0.2}$Ga$_{0.8}$N single which cm-^{3}[1x10 ^{19}/]-doped Si. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 3.2 kA/cm^{2} and the threshold voltage 4.8V, and, as for the other structure, the life also showed 30 hours or more.

[0091][Working example 6] As compared with working example 1, following (1) differs from (2), and also working example 6 is constituted like working example 1.

(1) Stop only TMG after buffer layer 11 growth, and raise temperature to 1050 **. If it becomes 1050 **, TMA, TMG, ammonia, and Silang will be used for material gas, The 1st layer that consists of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[1x10 ^{19}/]-doped Si is grown up by 60-A thickness, then Silang and the 2nd layer that stops TMA and consists of undoped GaN are grown up by 40-A thickness. and

1st layer + 2nd layer + 1st layer + 2nd layer + ... as -- superlattice layers are constituted, respectively the 1st layer is laminated to 500 layers, the 2nd layer is laminated alternately [500 layer], and the n side contact layer 12 which consists of superlattice of 5 micrometers of the total thickness is formed.

(2) Next, grow up the crack prevention layer 13 which consists of $In_{0.1}Ga_{0.9}N$ which cm^{-3}[5x10 ^{18}/]-doped Si like working example 1 by 500-A thickness. And temperature shall be 1050 ** and the n side clad layer 14 which consists of n type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[5x10 ^{18}/]-doped Si is grown up by 0.5 micrometer of thickness using TMA, TMG, ammonia, and Silang. Let tops be a laser device of working example 1, and a laser device which has the same structure from the next n side clad layer 14. That is, in the basic structure of Table 1, the n side contact layer 12 and the p side clad layer 19 are used as superlattice, and the laser device which makes 150 A thickness of the p side contact layer 20 like working example 1 is produced. This laser device was threshold current density 3.2 kA/cm^2 and the threshold voltage 4.8V, 405-nm continuous oscillation was checked and the life also showed 30 hours or more.

[0092]When the thickness of p side contact layer of the LD element of the structure of working example 6 is changed one by one, the relation between the

thickness of the p side contact layer and the threshold voltage of an LD element is shown in drawing 3. p side contact layer this sequentially from the left A (10 A or less), The threshold voltage in B (10 A), C (30 A), D (150 A, this example), E (500 A), F (0.2 micrometer), G (0.5 micrometer), and H (0.8 micrometer) is shown. As shown in this figure, when the thickness of p side contact layer exceeds 500 A, threshold voltage is in the tendency to go up gradually. As for the thickness of the p side contact layer 20, it is still more preferably desirable that it is 300 A or less 500 A or less. Since the surface of the lower p side clad layer 19 will be exposed if it becomes 10 A or less (2 atomic layers about 1 atomic layer, near), the contact resistance of p electrode worsens and threshold voltage tends to rise. However, in the LD element of this invention, since it has superlattice layers, threshold voltage is falling substantially compared with the thing of a comparative example.

[0093](Comparative example 2) The 1st layer that consists the n side clad layer 14 of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[1x10 ^{19}/]-doped Si in the laser device of the composition of Table 1 is grown up by 180-A thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 120-A thickness, and let it be a multilayer film of 0.6 micrometer of the total thickness. That is, when it

constituted from structure which thickened thickness of the 1st layer and the 2nd layer and the laser device was produced, continuous oscillation was checked by threshold current density 6.5 kA/cm^2, and threshold voltage was 7.5V. This laser device has gone out in several minutes.

[0094][Working example 7] The 1st layer that consists the p side clad layer 19 of $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg, and 60 A in working example 6, It is considered as the superstructure of 0.5 micrometer of the total thickness that laminated p type GaN which cm^{-3}[1x10 ^{20}/]-doped Mg, and the 2nd layer that consists of 40 A, and also the same laser device as working example 6 is produced. That is, when the thickness of the superlattice layers which constitute the p side clad layer 19 of working example 6 was changed and also the laser device was produced similarly, threshold voltage suited the tendency to go up a little as compared with the laser device of working example 6, but the life of 20 hours or more was shown.

[0095][Working example 8] The 1st layer that consists the n side clad layer 14 of n $typealuminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{19}/]-doped Si, and 60 A further in working example 7, It is considered as the superstructure of 0.5 micrometer of the total thickness that laminated n type GaN which cm^{-3}[1x10 ^{19}/]-doped Si,

and the 2nd layer that consists of 40 A, and also the same laser device as working example 7 is produced. That is, the laser device which used the n side clad layer as superlattice in addition to the n side contact layer 12 of working example 6 and the p side clad layer 19 had the characteristic almost equivalent to working example 6.

[0096][Working example 9] In working example 1, without growing up the 2nd buffer layer 112, as shown in Table 1, 5 micrometers of n type GaN layers which cm^{-3}[$1x10^{19}$/]-doped Si as the n side contact layer 12 directly on the 1st buffer layer 11 are grown up. Others are taken as the laser device which has the same structure as working example 1. That is, the 1st layer that consists the n side clad layer 14 of 20-A Si ($1x10^{19}/cm^3$) dope n type $aluminum_{0.2}Ga_{0.8}N$ in the basic structure of Table 1, It is considered as the superstructure of 0.4 micrometer of the total thickness that laminates the 2nd layer that consists of the 20-A undoping GaN. The 1st layer that furthermore consists the p side clad layer 19 of 20-A Mg ($1x10^{20}/cm^3$) doped p type $aluminum_{0.2}Ga_{0.8}N$, It is considered as the superstructure of 0.4 micrometer of the total thickness that laminates the 2nd layer that consists of the 20-A Mg ($1x10^{20}/cm^3$) doped p type GaN. When the p side contact layer 20 is used as the 150-A Mg ($2x10^{20}/cm^3$) doped p type GaN,

like working example 1 further again by threshold current density 3.3 kA/cm^2. 405-nm continuous oscillation was checked and, as for threshold voltage, 5.0V and a life also showed 30 hours or more.

[0097][Working example 10] In working example 9, the 2nd layer that constitutes the superlattice of the n side clad layer 14 is set to GaN which cm^{-3}[$1x10^{17}$/]-doped Si, and also the same laser device as working example 9 is produced. That is, the laser device which many Si was doped in the layer with larger bandgap energy, and also was produced like working example 9 in it showed the characteristic almost equivalent to working example 9.

[0098][Working example 11] In working example 9, the 2nd layer that constitutes the n side clad layer 14 is set to n type $In_{0.01}Ga_{0.99}N$ which cm^{-3}[$1x10^{19}$/]-doped Si, and also a laser device is produced similarly. That is, the laser device which set to InGaN the presentation of the 2nd layer that constitutes the superlattice of the n side clad layer 14, and impurity concentration of the 1st layer and the 2nd layer was made the same, and also was produced like working example 9 showed the characteristic almost equivalent to working example 9.

[0099][Working example 12] In working example 9, the thickness of the 1st layer (Si:$1x10^{19}/cm^3$ dope $aluminum_{0.2}Ga_{0.8}N$) that constitutes the n side clad layer 14

shall be 60 A, The 2nd layer is set to 40-A GaN which cm^{-3}[1x10 ^{19}/]-doped Si, and is made into the superstructure of 0.5 micrometer of the total thickness. The thickness of the 1st layer (Mg:1x10 ^{20}/cm^3 dope $aluminum_{0.2}Ga_{0.8}N$) that furthermore constitutes the p side clad layer 19 shall be 60 A, The thickness of the 2nd layer (Mg:1x10 ^{20} / cm^3 dope: GaN) shall be 40 A, and it is considered as the superstructure of 0.5 micrometer of the total thickness. That is, doped quantity of the 1st layer and the 2nd layer which constitutes the n side clad layer 14 is made the same, Change thickness, and change the thickness of the 1st layer and the 2nd layer which constitute the p side clad layer 19, and also. When the laser device was produced like working example 9, by threshold current density 3.4 kA/cm^2, 405-nm continuous oscillation was checked and, as for threshold voltage, 5.2V and a life also showed 20 hours or more.

[0100][Working example 13] The place which produced the laser device which Si concentration of the 2nd layer (GaN) that constitutes the n side clad layer 14 is made into 1x10 ^{17}/cm^3 in working example 11, and also has the same structure as working example 11, The laser device which has the characteristic almost equivalent to working example 11 has been produced.

[0101][Working example 14] In working example 11, when the laser device

which the 2nd layer (GaN) that constitutes the n side clad layer 14 is made undoped, and also has the same structure as working example 11 was produced, the laser device which has the characteristic almost equivalent to working example 11 has been produced.

[0102][Working example 15] In working example 9, 0.4 micrometer of n side clad layers 14 are grown up by the n type $aluminum_{0.2}Ga_{0.8}N$ single which cm^{-3}[1x10 ^{19}/]-doped Si, and also a laser device is produced similarly. That is, the 1st layer that consists only the p side clad layer 19 of p type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg like working example 1 in the basic structure of Table 1, It is considered as 20 A and the superstructure of 0.4 micrometer of the total thickness that consists of 20 A of the 2nd layer that consists of p type GaN which cm^{-3}[1x10 ^{19}/]-doped Mg, When the p side contact layer 20 is used as the 150-A Mg ($2x10^{20}/cm^3$) doped p type GaN like working example 1, similarly by threshold current density 3.4 kA/cm^2. 405-nm continuous oscillation was checked, threshold voltage showed 5.1V and the life showed 20 hours or more.

[0103][Working example 16] In working example 15, the 1st layer ($aluminum_{0.2}Ga_{0.8}N$) shall be 60 A the thickness of the superlattice layers which constitute the p side clad layer 19, When laminated the 2nd layer (GaN) as 40 A,

and it was considered as 0.5 micrometer of the total thickness and also the same laser device as working example 14 was obtained, threshold voltage suited the tendency to go up a little, but there were 20 hours or more of lives.

[0104][Working example 17] In working example 9, 0.4 micrometer of p side clad layers 19 are grown up by the p type aluminum$_{0.2}$Ga$_{0.8}$N single which cm^{-3}[1x10 ^{20}/]-doped Mg, and also a laser device is produced similarly. That is, the 1st layer that consists only the n side clad layer 14 of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm^{-3}[1x10 ^{19}/]-doped Si like working example 1 in the basic structure of Table 1, It is considered as 20 A and the superstructure of 0.4 micrometer of the total thickness that consists of 20 A of the 2nd layer that consists of undoped GaN, When the p side contact layer 20 is used as the 150-A Mg (2x10 ^{20}/cm^{3}) doped p type GaN like working example 1, similarly by threshold current density 3.5 kA/cm^{2}. 405-nm continuous oscillation was checked, threshold voltage showed 5.4V and the life showed 10 hours or more.

[0105][Working example 18] In working example 17, the 1st layer (aluminum$_{0.2}$Ga$_{0.8}$N) shall be 70 A the thickness of the superlattice layers which constitute the n side clad layer 14, In$_{0.01}$Ga$_{0.99}$N which cm^{-3}[1x10 ^{19}/]-doped Si for the 2nd layer, When laminated as 70 A, and it was considered as 0.49

micrometer of the total thickness and also the same laser device as working example 17 was obtained, compared with working example 16, threshold voltage suited the tendency to go up a little, but the laser device which similarly has a life of 10 hours or more was obtained.

[0106][Working example 19] In working example 17, the 1st layer (aluminum$_{0.2}$Ga$_{0.8}$N) shall be 60 A the thickness of the superlattice layers which constitute the n side clad layer 14, When laminated the 2nd layer (undoping GaN) as 40 A, and it was considered as 0.5 micrometer of the total thickness and also the same laser device as working example 16 was obtained, compared with working example 17, threshold voltage suited the tendency to go up a little, but the laser device which similarly has a life of 10 hours or more was obtained.

[0107][Working example 20] In working example 9, it is considered as the 2nd layer that will be the 1st layer that consists the n side light guide layer 15 of undoped GaN further, and 20 A from undoped $In_{0.1}Ga_{0.9}N$, and the superlattice layers of 800 A of the total thickness that laminates 20. Besides, in addition, the p side light guide layer 18 is also made into the superstructure of 800 A of the total thickness that laminates the 1st layer that consists of undoped GaN, 20 A, and the 2nd layer that consists of undoped $In_{0.1}Ga_{0.9}N$, and 20 A. That is, in the

basic structure of Table 1, the n side clad layer 14, the n side light guide layer 15, the p side light guide layer 18, and the p side clad layer 19 are made into a superstructure, When the p side contact layer 20 is used as the 150-A Mg (2x10 ^{20}/cm^{3}) doped p type GaN, like working example 1 further again by threshold current density 2.9 kA/cm^{2}. 405-nm continuous oscillation was checked and, as for threshold voltage, 4.4V and a life also showed 60 hours or more.

[0108][Working example 21] This example is described based on the LED element of drawing 1. The buffer layer 2 which comes from GaN on the substrate 1 which consists of sapphire like working example 1 is grown up by 200-A thickness, Subsequently, the contact layer which consists of n type GaN which cm^{-3}[1x10 ^{19}/]-doped Si is grown up by 5-micrometer thickness, and the active layer 4 which consists of single quantum well structure of 30 A of thickness which consists of $In_{0.4}Ga_{0.6}N$ next is grown up.

[0109]The 1st layer that consists of p type aluminum$_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg like the (p side superlattice layers), next working example 1 is grown up by 20-A thickness, Then, the 2nd layer that consists of p type GaN which cm^{-3}[1x10 ^{19}/]-doped Mg is grown up by 20-A thickness, and the p side clad layer 5 which consists of superlattice of 0.4 micrometer of the total thickness

is grown up. Although the thickness in particular of this p side clad layer 4 is not limited, either, it is desirable to make it grow up at 500 A or more and 1 micrometer or less still more preferably 2 micrometers or less 100 A or more.

[0110]Next, the p type GaN layer which cm^{-3}[$1x10^{20}$/]-doped Mg on this p side clad layer 5 is grown up by 0.5 micrometer of thickness. After growth, after picking out a wafer from a reaction vessel and performing annealing like working example 1, the surface of the n side contact layer 3 which should perform etching from the p side contact layer 6 side, and should form the n electrode 9 is exposed. The p electrode 7 of the translucency which consists of nickel-Au of 200 A of thickness all over almost [of the p side contact layer 6 of the top layer] is formed, and the p pad electrode 8 which consists of Au(s) is formed on the whole surface electrode 7. The n electrode 9 which consists of Ti-aluminum is formed also in the surface of exposed n side contact layer.

[0111]When the wafer which formed the electrode as mentioned above was divided into the chip of a 350-micrometer angle and it was considered as the LED element, 520-nm green emission was shown in If20mA, and Vf was 3.2V. On the other hand, Vf of the LED element which constituted the p side clad layer 5 from single Mg-dope $aluminum_{0.2}Ga_{0.8}N$ was 3.4V. Furthermore, in

electrostatic pressure-proofing, the direction of this example had electrostatic pressure-proofing of more than twice.

[0112][Working example 22] in working example 21, the superlattice layers which constitute the p side clad layer 5, The thickness of the 1st layer shall be 50 A and the 2nd layer as GaN which cm^{-3}[$1x10^{20}$/]-doped Mg, and 50 A, 25 layers were laminated, respectively, and when it was considered as the superlattice of 0.25 micrometer of the total thickness and also the LED element was created similarly, the LED element which has the characteristic almost equivalent to working example 21 was obtained.

[0113][Working example 23] In working example 21, 100 A of the 1st layer, and the 2nd layer for the thickness of the superlattice layers which constitute the p side clad layer 5 as 70-A thickness, When it was considered as the superlattice of 0.25 micrometer of the total thickness and also the LED element was created similarly, Vf was 3.4V, but electrostatic pressure-proofing was superior to the conventional thing not less than 20%.

[0114][Working example 24] When growing up the n side contact layer 3 in working example 21, The 1st layer that consists of n type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[$2x10^{19}$/]-doped Si 60 A, The 2nd layer that consists of undoped

GaN is grown up by 40-A thickness, respectively the 1st layer is laminated to 500 layers, the 2nd layer is laminated alternately [500 layer], and it is considered as the superlattice of 5 micrometers of the total thickness. When others produced the LED element like working example 12, similarly, in If20mA, Vf fell to 3.1V, and comparison comparison was carried out and it acted to 2.5 or more times as Kougami of the electrostatic pressure-proofing at the former.

[0115][Working example 25] In working example 23, the thickness of the 1st layer (aluminum$_{0.2}$Ga$_{0.8}$N) of the superlattice which constitutes the p side clad layer 5 shall be 60 A, and the thickness of the 2nd layer shall be 40 A, When the LED element which laminate alternately [25 layer], respectively, and it is considered as 0.3 micrometer of the total thickness, and also has the same structure was produced, Vf was 3.2V and electrostatic pressure-proofing was more than twice over the past.

[0116][Working example 26] This example is described based on the laser device shown in drawing 4. Although it is a sectional view at the time of drawing 4 as well as drawing 2 cutting an element in a direction vertical to the resonant direction of a laser beam, A different place from drawing 2 is one of the place which uses the substrate 101 which turns into the substrate 10 from GaN, and

the places into which the 3rd buffer layer 113 that doped the n type impurity is grown up without growing up the 2nd buffer layer 112. The laser device shown in this drawing 4 is obtained by the following methods.

[0117]MOVPE method or the HVPE method is first used on silicon on sapphire, after growing up the GaN layer which cm^{-3}[5x10 ^{18}/]-doped Si at 300 micrometers in thickness, silicon on sapphire is removed and the 300-micrometer-thick Si-dope GaN board 101 is produced. The GaN board 101 is obtained by removing the different-species board, after making it grow up by not less than 100-micrometer thickness on a different substrate in this way from a nitride semiconductor for example. Undoping may be sufficient as the GaN board 101, and it may dope and produce a n type impurity. If it usually dopes an impurity in the range of 1x10 $^{17}/cm^3$ - 1x10 $^{19}/cm^3$ in doping a n type impurity, a good crystalline GaN board will be obtained.

[0118]Temperature shall be 1050 ** after GaN board 101 production, and the 3rd buffer layer 113 that consists of n type GaN which cm^{--3}[3x10 ^{18}/]-doped Si is grown up by 3-micrometer thickness. Although the 3rd buffer layer 113 is a layer which is equivalent to the n side contact layer 14 in drawing 1 and drawing 2, since it is not a layer which forms an electrode, it does not call it a contact layer

here, but calls it the 3rd buffer layer 113. Although the 1st buffer layer grown up at low temperature like working example 1 between the GaN board 101 and the 3rd buffer layer 113 may be grown up, when growing up the 1st buffer layer, it is desirable to use 300 A or less.

[0119]Next, the crack prevention layer 13 which consists of $In_{0.1}Ga_{0.9}N$ which cm^{-3}[5x10 ^{18}/]-doped Si like working example 1 on the 3rd buffer layer 113 is grown up by 500-A thickness. Next, the 1st layer and 20 A which consists of n type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[5x10 ^{18}/]-doped Si, The n side clad layer 14 which consists of superlattice layers of 0.4 micrometer of the total thickness which laminated alternately 20 A of the 2nd layer that consists of GaN which cm^{-3}[5x10 ^{18}/]-doped Si 100 times is grown up. Next, the n side light guide layer 15 which consists of n type GaN which cm^{-3}[5x10 ^{18}/]-doped Si like working example 1 is grown up by 0.1 micrometer of thickness.

[0120]Next, the well layer and 25 A which consists of undoping $In_{0.2}Ga_{0.8}N$, 50 A of barrier layers which consist of the undoping GaN are grown up, and the active layer 16 of the multiple quantum well structure (MQW) of 175 A of the total thickness that finally laminated the well layer is grown up twice repeatedly by turns.

[0121]Next, the p side cap layer 17 which consists of p type aluminum$_{0.3}$Ga$_{0.7}$N which cm-^{3}[1x10 ^{20}/]-doped Mg like working example 1 is grown up by 300-A thickness, The p side light guide layer 18 which consists of p type GaN which cm-^{3}[1x10 ^{20}/]-doped Mg is grown up by 0.1 micrometer of thickness.

[0122]Next, the 1st layer and 20 A which consists of p type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[1x10 ^{20}/]-doped Mg like working example 1, The 2nd layer that consists of p type GaN which cm-^{3}[1x10 ^{20}/]-doped Mg, The p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness which consist of 20 A is formed, The p side contact layer 20 which finally consists of p type GaN which cm-^{3}[2x10 ^{20}/]-doped Mg on the p side clad layer 19 is grown up by 150-A thickness.

[0123]After ending reaction and after carrying out annealing at 700 **, like working example 1, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has the stripe width of 4 micrometers.

[0124]Next, the p electrode 21 which consists of nickel and Au as well as working example 1 all over almost [of the stripe ridge outermost surface of the p side contact layer 20] is formed, and the n electrode 23 which consists of Ti and

aluminum is formed all over almost [of the rear face of the GaN board 101].

[0125]Next, as shown in drawing 4, the insulator layer 25 which consists of SiO_2 of the p side clad layer 19 excluding the area of the p electrode 21 is formed, and the p pad electrode 22 electrically connected with the p electrode 21 is formed via this insulator layer 25.

[0126]Cleavage of the GaN board 101 is carried out to bar shape in a direction vertical to the p electrode 21 after electrode formation, and a resonator is produced to a cleavage plane. The cleavage plane of a GaN board is made into M side. The dielectric multilayer which consists of SiO_2 and TiO_2 was formed in the cleavage plane, and it was considered as the laser chip which cuts a bar and is finally shown in drawing 4 in a direction parallel to p electrode. Next, in [when the chip was installed in the heat sink by face up (state which the substrate and the heat sink countered), wire bonding of the p pad electrode 22 was carried out and laser oscillation was tried at the room temperature] a room temperature, With threshold current density 2.5 kA/cm^2 and the threshold voltage 4.0V, continuous oscillation with an oscillation wavelength of 405 nm was checked, and the life of 500 hours or more was shown. By having used GaN for the substrate, this is because the breadth of the crystal defect decreased.

[0127]

[Effect of the Invention]As explained above, since the nitride semiconductor device concerning this invention is constituted using superlattice layers, it can improve power efficiency extremely in p type nitride semiconductor fields or n type nitride semiconductor fields other than an active layer. That is, although making an active layer into multiple quantum well structure was proposed in the conventional nitride semiconductor device, the active layer was inserted, for example, usually cladding layers comprised a single nitride semiconductor layer. However, in the nitride semiconductor device of this invention, since the superlattice layers which have the layer that a quantum effect appears are provided as a cladding layer or a contact layer which pours in current, resistivity by the side of a cladding layer can be made low. By this, the threshold current of an LD element and threshold voltage can be made low, for example, and this element can be made long lasting. Although the further conventional LED was weak to static electricity, in this invention, an element strong against electrostatic pressure-proofing is realizable. Thus, since Vf and threshold voltage are made low, calorific value can also decrease and the reliability of this element can also be raised. According to the nitride semiconductor device of this invention, not to

mention light emitting devices, such as LED and LD, when it uses for a solar cell, a photosensor, a transistor, etc. which used the nitride semiconductor, it becomes possible to realize a device with high efficiency of an emergency, and the industrial utility value is dramatically large.

TECHNICAL FIELD

[Field of the Invention]This invention Light emitting devices, such as LED (light emitting diode) and LD (laser diode), It is related with the element which consists of a nitride semiconductor ($In_XAl_YGa_{1-X-Y}N$, 0<=X, 0<=Y, X+Y<=1) used for electron devices, such as photo detectors, such as a solar cell and a photosensor, or a transistor. a layer which general formula $In_XGa_{1-X}N$, $aluminum_YGa_{1-Y}N$, etc. which are used in this Description only show the empirical formula of a nitride semiconductor layer, and is different -- for example, even if shown by the same general formula, It is not shown till the X value of those layers and Y value being in agreement.

PRIOR ART

[Description of the Prior Art]The nitride semiconductor was just put in practical use with a full color LED display, a traffic signal, etc. as a material of high-intensity blue LED and authentic green LED recently. LED used for these various devices has terrorism structure to the double into which the active layer which consists of InGaN of single quantum well structure (SQW:Single-Quantum- Well) between a n type nitride semiconductor layer and a p type nitride semiconductor layer was inserted. Wavelength, such as blue and green, is determined by fluctuating In composition ratio of an InGaN active layer. [0003]These people announced the 410-nm laser oscillation in the room temperature for the first time under pulse current in the world recently using this material (for example, Jpn.J.Appl.Phys. Vol35 (1996) pp.L74-76). This laser device is the conditions of 2 microseconds of pulse width, and 2 ms of pulse cycles, and shows the threshold current of 610 mA, threshold current density 8.7 kA/cm^2, and a 410-nm oscillation. The threshold current announced the improved low laser device further again in Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, and p.1477-1479. This laser device has the structure where the ridge

stripe was formed in a part of p type nitride semiconductor layer.

1 microsecond of pulse width, 1 ms of pulse cycles, and 0.1% of duty ratio show the threshold current of 187 mA, threshold current density 3 kA/cm^2, and a 410-nm oscillation.

EFFECT OF THE INVENTION

[Effect of the Invention]As explained above, since the nitride semiconductor device concerning this invention is constituted using superlattice layers, it can improve power efficiency extremely in p type nitride semiconductor fields or n type nitride semiconductor fields other than an active layer. That is, although making an active layer into multiple quantum well structure was proposed in the conventional nitride semiconductor device, the active layer was inserted, for example, usually cladding layers comprised a single nitride semiconductor layer. However, in the nitride semiconductor device of this invention, since the superlattice layers which have the layer that a quantum effect appears are provided as a cladding layer or a contact layer which pours in current, resistivity

by the side of a cladding layer can be made low. By this, the threshold current of an LD element and threshold voltage can be made low, for example, and this element can be made long lasting. Although the further conventional LED was weak to static electricity, in this invention, an element strong against electrostatic pressure-proofing is realizable. Thus, since Vf and threshold voltage are made low, calorific value can also decrease and the reliability of this element can also be raised. According to the nitride semiconductor device of this invention, not to mention light emitting devices, such as LED and LD, when it uses for a solar cell, a photosensor, a transistor, etc. which used the nitride semiconductor, it becomes possible to realize a device with high efficiency of an emergency, and the industrial utility value is dramatically large.

TECHNICAL PROBLEM

[Problem to be solved by the invention]The blue and green LED which consist of nitride semiconductors are forward current (If)20mA, and compared with red LED which forward voltage (Vf) becomes from the semiconductor of 3.4V - those with 3.6V, and a GaAlAs system, as for more than 2V, since it is high, a fall of

further Vf is desired. In LD, the current in a threshold value and voltage are still high, and in order to carry out continuous oscillation at a room temperature, it is necessary to realize the element that this threshold current and voltage fall and that power efficiency is still higher.

[0005]Therefore, by reducing the current in the threshold value of the LD element which mainly consists of nitride semiconductors, and voltage, the place made into the purpose of this invention realizes continuous oscillation, and reduces Vf in a LED element, is reliable, and there is in realizing the nitride semiconductor device excellent in power efficiency.

MEANS

[Means for solving problem]As a result of examining a nitride semiconductor device wholeheartedly that the p type layer which sandwiched the active layer, and/or a n type layer should be improved, this invention persons by using superlattice layers for the p type layer except an active layer, and/or a n type layer, The crystallinity of the layer using superlattice layers can be made good, and it newly finds out that said problem is solvable, and came to accomplish this invention.

[0007]Namely, the 1st nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor which said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers. Since the resistance of the p type nitride semiconductor layer which consists of said superlattice layers can be made very low by this, power efficiency of a nitride semiconductor device can be made high. In the 1st nitride semiconductor device concerning this invention, said superlattice layers, Since the 2nd layer that consists of a nitride semiconductor which the 1st layer, this 1st layer, and presentation which consist of a nitride semiconductor which has thickness of 100A or less differ from each other, and has thickness of 100A or

less is laminated, the crystallinity of said superlattice layers can improve. the threshold current by applying a superstructure to a p type cladding layer, and voltage -- it seems to be low -- ****** can be large and a threshold current and voltage can be notably reduced in this invention.

[0008]It is preferred to dope a p type impurity in the 1st nitride semiconductor device concerning this invention in either [at least] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 1st nitride semiconductor device of the above, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0009]The 2nd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one. It has

thickness of 100A or less at not less than 10A, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0010]In the 2nd nitride semiconductor device concerning this invention, when said p side clad layers are said superlattice layers, It is preferred to dope a p type impurity in either [at least] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 2nd nitride semiconductor device concerning this invention, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0011]In the 2nd nitride semiconductor device concerning this invention, when said n side clad layers are said superlattice layers, It is preferred to dope a n type impurity in either [at least] said 1st layer or said 2nd layer, and it is preferred that the concentration of the n type impurity doped without the 1st layer of an account and said 2nd layer differs mutually. Under the present

circumstances, when the bandgap energy of said 1st layer and said 2nd layer differs mutually, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0012]The 3rd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, The 3rd layer that consists of a nitride semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 3rd layer, and it has thickness of 100A or less at not less than 10A, and the 4th layer that consists of a nitride

semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0013]It may be made to form a Mine-like ridge part in a resonant direction in the 3rd nitride semiconductor device of the above in the layer currently formed above said p side clad layer and this p side clad layer.

[0014]In the 1st concerning this invention - the 3rd nitride semiconductor device, said active layer may have a nitride semiconductor containing indium. Said 1st [the] - the 3rd nitride semiconductor device, It may be made to form on C side of silicon on sapphire, and after said 1st [the] - the 3rd nitride semiconductor device grow up the GaN layer which doped Si on C side of silicon on sapphire, it may be made to form them on the GaN board from which silicon on sapphire was removed. In said 1st [the] - the 3rd nitride semiconductor device, said n side light guide layer may be GaN, and may be InGaN. In said 1st [the] - the 3rd nitride semiconductor device, said p side light guide layer may be GaN, and may be InGaN. Said active layer is touched in said 1st [the] - the 3rd nitride semiconductor device, It is preferred to provide the p side light guide layer in which bandgap energy is smaller than said p side cap layer in the position which has the p side cap layer which consists of a nitride semiconductor containing

aluminum, and is separated from an active layer rather than the p side cap layer.

[0015]The 1st layer that consists superlattice layers of $In_XGa_{1-X}N$ (0<=X<=1) in the 1st - the 3rd nitride semiconductor device of this invention, If constituted by laminating the 2nd layer that consists of $aluminum_YGa_{1-Y}N$ (0<=Y<=1, X=Y!=0), General formula $aluminum_YGa_{1-}$ Since a good crystalline semiconductor layer is obtained, the nitride semiconductor expressed with $_YN$ and $In_XGa_{1-X}N$ can form a layer with few crystal defects. Thereby, the crystallinity of the whole nitride semiconductor becomes good, and when improvement (improvement in power efficiency) and this element are a LED element or an LD element about the output of this element, Vf, a threshold current, voltage, etc. can be made low. In the 1st of this invention - the 3rd nitride semiconductor device. In said superlattice layers in order to form a layer with still few crystal defects, It is still more preferred that said 1st layer consists of a nitride semiconductor expressed with formula $In_XGa_{1-X}N$ (0<=X<1), and said 2nd layer consists of a nitride semiconductor expressed with formula $aluminum_YGa_{1-Y}N$ (0< Y<1).

[0016]In the 1st - the 3rd nitride semiconductor device of this invention, although it is preferred that it is 70A or less as mentioned above as for the thickness of said 1st layer and the 2nd layer, it is set as 40A or less still more preferably. In

this invention, the thickness of said 1st layer and the 2nd layer is set as not less than 10A. By setting up within the limits of this, nitride semiconductor layers, such as aluminum$_Y$Ga$_{1-Y}$N (0< Y<=1) which was hard to grow up, can form with sufficient crystallinity by the former. Of the p type nitride semiconductor layers which are between p electrode and an active layer especially, at least further, And/or, when making into superlattice layers at least one layer in the n type nitride semiconductor layer between n side contact layer as a current injection layer and the active layer in which n electrode is formed, the effect by setting the 1st layer that constitutes the superlattice layers, and the 2nd layer as said thickness is large.

[0017]In the 1st - the 3rd nitride semiconductor device of this invention, it is preferred to have p side contact layer for forming p electrode, and to set the thickness of these p side contact layers as 500A or less. Thus, the resistance of the thickness direction of these p side contact layers can be lowered by forming p side contact layer thinly. It is still more preferred to set it as 300A or less in this invention. As for the minimum of the thickness of these p side contact layers, it is preferred to set it as not less than 10A so that the semiconductor layer under this p type contact layer may not be exposed.

[0018]moreover -- forming the 1st buffer layer on a substrate and forming on it the 2nd buffer layer that consists of a nitride semiconductor of 0.1 micrometers or more of thickness in this invention, -- this -- it is preferred to form n side contact layer which consists of a nitride semiconductor with which a n type impurity was doped on the 2nd buffer layer. By this, carrier concentration can form good large crystalline n side contact layer. In order to form said 2nd buffer layer with still more sufficient crystallinity, it is preferred that impurity concentration of said 2nd buffer layer is low concentration as compared with said n side contact layer.

[0019]In this invention, as an impurity which determines a conductivity type, the [which is doped by nitride semiconductor / periodic table] -- the [4A fellows, 4B fellows, and] -- the [6A fellows and] -- there are a n type impurity belonging to 6B fellows and a p type impurity belonging to 1A, 1B fellows, 2A fellows, and 2B fellows (this Description is hereafter described as a n type impurity and a p type impurity suitably.). As mentioned above, when bandgap energy differs in the 1st layer and 2nd layer, it is desirable to enlarge impurity concentration of a layer with larger bandgap energy. By this, a high increase in power by an abnormal-conditions dope at the time of forming superlattice layers in the p type

nitride semiconductor layer side is expectable. In this invention, n side contact layers may be superlattice layers. Bandgap energy can differ mutually in two layers which constitute superlattice layers which are n side contact layers, and power efficiency can be raised by enlarging impurity concentration of a layer with larger bandgap energy by an effect which was similar to HEMT mentioned later. For example, in a laser device, it is in threshold voltage and a tendency for a threshold current to fall, further.

[0020]

[Mode for carrying out the invention]Hereafter, a nitride semiconductor device of an embodiment which starts this invention with reference to Drawings is explained.

Embodiment 1. drawing 1 is structure of a nitride semiconductor device of Embodiment 1 concerning this invention a shown typical sectional view, and this nitride semiconductor device, As a fundamental structure, on the substrate 1 which consists of sapphire, The buffer layer 2 which consists of GaN(s), the n side contact layer 3 which consists of Si-dope n type GaN, the active layer 4 which consists of InGaN of single quantum well structure, the p side clad layer 5 which consists of superlattice layers by which the 1st layer that differs in a

presentation mutually, and the 2nd layer were laminated, The p side contact layer 6 which consists of Mg dope GaN is the LED element laminated in order. In a nitride semiconductor device of Embodiment 1, all over almost [of the p side contact layer 6 surface], The whole surface electrode 7 of translucency is formed, the p electrode 8 for bonding is formed in the surface of the whole surface electrode 7, and the n electrode 9 is formed in the surface of the n side contact layer 2 further exposed from the p side contact layer 6 by carrying out etching removal of a part of nitride semiconductor layer.

[0021]The 1st layer of 30 A of thickness (A) which consists of $In_XGa_{1-X}N$ (0<=X<=1) in which the nitride semiconductor device of Embodiment 1 doped Mg, for example as a p type impurity here, Since it has the p side clad layer 5 which has the low resistance which comprised superlattice layers by which the 2nd layer of 30 A of thickness which consists of p type $aluminum_YGa_{1-Y}N$ (0<=Y<=1) which similarly doped Mg in the 1st layer and tales doses as a p type impurity was laminated, Vf can be made low. Thus, when forming superlattice layers in the p layer side, it is considered as the superlattice layers which dope p type impurities, such as Mg, Zn, Cd, and Be, in the 1st layer and/or the 2nd layer, and have a p type conductivity type. as laminating order -- the -- the [1+] -- the

[2+the 1st ... or, and] -- the [2+] -- the order of 1+the 2nd ... may be sufficient, and at least a total of two or more layers are laminated.

[0022]The 1st layer and 2nd layer that consist of a nitride semiconductor which constitutes superlattice layers, It is not necessarily limited to the layer which consists of the layer and aluminum$_Y$Ga$_{1-Y}$N ($0<=Y<=1$) which consist of In$_X$Ga$_{1-X}$N ($0<=X<=1$), and what is necessary is just to comprise a nitride semiconductor with which presentations differ mutually. The bandgap energy of the 1st layer and the 2nd layer may differ, or it may be the same. For example, if the 1st layer is constituted from In$_X$Ga$_{1-X}$N ($0<=X<=1$) and the 2nd layer is constituted from aluminum$_Y$Ga$_{1-Y}$N ($0< Y<=1$), the bandgap energy of the 2nd layer will certainly become larger than the 1st layer, but. If the 1st layer is constituted from In$_X$Ga$_{1-X}$N ($0<=X<=1$) and the 2nd layer is constituted from In$_Z$Al$_{1-Z}$N ($0< Z<=1$), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation. If the 1st layer is constituted from aluminum$_Y$Ga$_{1-Y}$N ($0<=Y<=1$) and the 2nd layer is constituted from In$_Z$Al$_{1-Z}$N ($0< Z<=1$), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation similarly. That is, as long as this invention is superlattice layers which have the operation mentioned later, its bandgap energy of the 1st

layer and the 2nd layer may be the same, or they may differ. As mentioned above, since [which differs in a presentation] a film is laminated extremely and the thickness of each layer is thin enough, the superlattice layers said here are large concepts which say the thing of the layer laminated without the defect accompanying a stacking fault occurring, and include quantum well structure. Although these superlattice layers do not have a defect inside, since they have the distortion accompanying a stacking fault, they are also usually called a strained super lattice. In this invention, even if V group elements, such as As and P, replace a part of N (nitrogen) of the 1st layer and the 2nd layer, as long as N exists, it is contained in a nitride semiconductor.

[0023]In this invention, the thickness of the 1st layer and the 2nd layer which constitutes superlattice layers, Since the 1st layer and 2nd layer will serve as thickness beyond an elastic strain limit and a very small crack or a crystal defect will enter easily into this film if thicker than 100 A, it is preferred to set it as thickness of 100 A or less. The minimum in particular of the thickness of the 1st layer and the 2nd layer is not limited, but should just be one or more atomic layers. However, in this invention the thickness of the 1st layer and the 2nd layer, The critical (elastic strain) marginal thickness of a nitride semiconductor is not

fully reached as it is 100 A, It is most preferred for setting it as 70 A or less to set up desirable still more desirable more thinly, in order to use below elastic strain marginal thickness and to lessen the crystal defect of a nitride semiconductor more, and to set it as 40 A - 10 A. Although it may be set as 10 A or less (one atomic layer or two atomic layers) in this invention, if it is set as 10 A or less, For example, as for the thickness of the 1st layer and the 2nd layer, since formation time and time and effort are taken on ** more than which the number of laminations increases, and a manufacturing process when forming the cladding layer of thickness of 500 A or more by superlattice layers, it is preferred to set up more thickly than 10 A.

[0024]In the case of the nitride semiconductor device of this Embodiment 1 shown in drawing 1, the p type clad layer 5 which consists of superlattice layers is formed between the active layer 4 and the p side contact layer 6 which is current injection layers, and is acting as a carrier confining layer. Thus, to make especially superlattice layers into a carrier confining layer, it is necessary to make average bandgap energy of superlattice layers larger than an active layer. In a nitride semiconductor, since the nitride semiconductor containing aluminum, such as AlN, AlGaN, and InAlN, has comparatively big bandgap energy, these

layers are used as a carrier confining layer. However, if a thick film is grown up by an AlGaN single like before, it has the character in which a crack enters easily into crystal growth.

[0025]Then, the nitride semiconductor which contains aluminum at least in this invention for either [at least] the 1st layer of superlattice layers, or the 2nd layer, By forming aluminum$_Y$Ga$_{1-Y}$N (0< Y<=1) by the thickness below an elastic strain limit preferably, and constituting superlattice layers, growth formation of the good crystalline superlattice layers is carried out very much, and bandgap energy forms the layer big moreover with few cracks. In this case, it is made hard to act also as a buffer layer at the time of growing up the 2nd layer that consists of a nitride semiconductor containing aluminum, if the nitride semiconductor layer which does not contain aluminum in the 1st layer is grown up by thickness of 100 A or less still more preferably, and to go into the 2nd layer in a crack. Therefore, even if it laminates the 1st layer and 2nd layer, good crystalline superlattice layers without a crack can be formed. Therefore, in this Embodiment 1, it is preferred to use superlattice layers as the 1st layer (the 2nd layer) that consists of In$_X$Ga$_{1-X}$N (0<=X<=1), and the 2nd layer (the 1st layer) that consists of aluminum$_Y$Ga$_{1-Y}$N (0<=Y<=1, X!=Y=0).

[0026]In the nitride semiconductor device of this Embodiment 1, in order to adjust carrier concentration to at least one layer of the 1st layer and the 2nd layer which constitute the p side clad layer 5 which is superlattice layers, it is preferred that the p type impurity which sets the conductivity type of this layer as a p type is doped. Dope ** is also good by the concentration in which the 1st layer differs from the 2nd layer when doping a p type impurity in the 1st layer and 2nd layer, and when the bandgap energy of the 1st layer and the 2nd layer differs, it is still more desirable for bandgap energy to make the big layer high concentration. It is because the carrier concentration of one layer can become high substantially and the resistance of the whole superlattice layers can be reduced according to the quantum effect by abnormal-conditions doping, if an impurity is doped by concentration which is different in the 1st layer and the 2nd layer, respectively. Thus, in this invention, an impurity may be doped by different concentration in both the 1st layer and the 2nd layer, respectively, and an impurity may be doped in the 2nd either one of 1st layer or layer.

[0027]The impurity concentration doped by the 1st layer and 2nd layer, Although this invention in particular is not limited to this, usually with a p type impurity $1 \times 10^{16}/cm^3$ - $1 \times 10^{22}/cm^3$, It is still more preferably desirable $1 \times 10^{17}/cm^3$ - $1 \times 10^{21}/cm^3$,

and to adjust to the range of $1x10^{18}/cm^3$ - $2x10^{20}/cm^3$ most preferably. It is because it is in the tendency for the crystallinity of superlattice layers to worsen when more [if less than $1x10^{16}/cm^3$, the effect of reducing Vf and threshold voltage will be hard to be acquired, and] than $1x10^{22}/cm^3$. It is desirable to also adjust a n type impurity to the same range. The Reason is the same.

[0028]However, in this invention, the impurity which determines a conductivity type as the 1st layer and 2nd layer does not need to be doped by superlattice layers. The superlattice layers by which this impurity is not doped may be which layers between an active layer and a substrate, as long as they are n type nitride semiconductor layer fields, and on the other hand, as long as they are p type nitride semiconductor layer fields, they may be which layers between a carrier confining layer (optical confinement layer) and an active layer.

[0029]Since the 1st layer and the 2nd layer are made into the thickness below an elastic strain limit, are laminated and the superlattice layers constituted as mentioned above form them, the lattice defect of a crystal can be reduced, and they can decrease a very small crack, and can improve crystallinity fast. As a result, without spoiling crystallinity not much, increase doped quantity of an impurity for it and by this. Since it can move without being able to make the

carrier concentration of a n type nitride semiconductor layer and a p type nitride semiconductor layer increase, and scattering about these carriers according to a crystal defect, as compared with the nitride semiconductor of a p type or a n type which does not have a superstructure, single or more figures resistivity can be made low.

[0030]Therefore, in the nitride semiconductor device (LED element) of this Embodiment 1. Obtaining a low resistance nitride semiconductor layer conventionally forms the p type clad layer 5 by the side of difficult p layer (p type semiconductor layer field (field which consists of the p type clad layer 5 and the p type contact layer 6)) using superlattice layers, By making low the resistance of this p type clad layer 5, Vf can be made low. That is, compared with a n type nitride semiconductor, resistivity is usually high [a p type nitride semiconductor / a p type crystal is a semiconductor which is very hard to be obtained, and], even if a p type nitride semiconductor is obtained double or more figures. Therefore, by forming p type superlattice layers in the p layer side, the p type layer which comprised superlattice layers can be extremely made into low resistance, and the fall of Vf appears notably. in order to obtain a p type crystal conventionally, annealing of the nitride semiconductor layer which doped the p type impurity is

carried out as technology, and the technology which produces a p type nitride semiconductor is known by removing hydrogen (patent No. 2540791). However, although the p type nitride semiconductor was obtained, the resistivity has more than number omega and cm. Then, crystallinity becomes good by making this p type layer into p type superlattice layers, according to our examination, this p layer resistivity [single or more figures] can be made low as compared with the former, and the effect that Vf makes it fall shows up notably.

[0031]In this Embodiment 1, the 1st layer (the 2nd layer) is preferably set to $In_XGa_{1-X}N$ (0<=X<=1) as mentioned above, Since the superlattice layers which do not have a good crystalline crack by constituting the 2nd layer (the 1st layer) from $aluminum_YGa_{1-Y}N$ (0<=Y<=1, X!=Y=0) can be formed, an element life can be raised.

[0032]Next, we compare and explain the conventional example and this invention which were indicated by publicly known document containing the Patent Gazette for which it applied before. First, we proposed JP,H8-228048,A previously as technology similar to this invention. This technology is technology which forms the multilayer film which becomes the outside of the n type clad layer which sandwiches an active layer, and/or the outside (that is, side which is

separated from an active layer) of a p type clad layer from AlGaN, GaN, InGaN, etc. as a light reflection film of a laser beam. Since a multilayer film is formed as a light reflection film, and the thickness of that each layer is designed by lambda / 4n (n: the refractive index of a nitride semiconductor, lambda:wavelength), this technology is dramatically thick. Therefore, each thickness of a multilayer film is not the thickness below an elastic strain limit. The laser device of the structure which inserted the active layer into USP No. 5,146,465 by the mirror which consists of aluminum$_X$Ga$_{1-X}$N/aluminum$_Y$Ga$_{1-Y}$N is indicated. In order to make AlGaN/AlGaN act as a mirror like [this technology] last technology, thickness of each layer must be thickened. It is dramatically difficult to laminate a many layers hard semiconductor still like AlGaN without a crack.

[0033]On the other hand, each thickness of the 2nd layer is set to the 1st constitute superlattice layers from this embodiment (both are preferably set to 100 A or less and below critical thickness.), and it differs from said technology. The effect by the strained super lattice of the nitride semiconductor which constitutes superlattice layers from this invention is used, crystallinity is raised, and Vf is reduced.

[0034]The method of laminating AlN and GaN of a thin film to JP,5-110138,A

and JP,H5-110139,A, and obtaining the crystal of aluminum$_Y$Ga$_{1-Y}$N is indicated. In order to obtain the mix crystal of aluminum$_Y$Ga$_{1-Y}$N of a predetermined mixed crystal ratio, this technology is technology which laminates AlN of tens of A thickness, and GaN, and differs from the technology of this invention. And since it does not have an active layer which consists of InGaN(s), a crack goes into superlattice layers easily. The light emitting device of terrorism structure is indicated by JP,H6-21511,A and the No. 268257 [six to] gazette to the double which has an active layer of the multiple quantum well structure which laminated GaN, InGaN or InGaN, and InGaN. In this invention, it is the technology which makes layers other than an active layer multiple quantum well structure, and differs also from this technology.

[0035]Furthermore, with the element of this invention, when equipping an active layer with a nitride semiconductor like InGaN which contains indium at least, the effect of superlattice shows up notably. Bandgap energy is small and the InGaN active layer is most suitable as an active layer of a nitride semiconductor device. Therefore, since an active layer, a bandgap energy difference, and refractive index difference can be enlarged if the superlattice layers which consist of In$_X$Ga$_{1-X}$N and aluminum$_Y$Ga$_{1-Y}$N are formed as a layer which sandwiches an

active layer, When these superlattice layers realize a laser device, it operates as a dramatically outstanding optical confinement layer (it applies to the nitride semiconductor device of Embodiment 2). Since InGaN is [the character of a crystal] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. Conversely, when a nitride semiconductor like AlGaN is made into an active layer, since the character of the crystal is hard, it is in the tendency for a crack to go into the whole crystal easily.

[0036]It is desirable to adjust still more preferably 500 A or less of thickness [300 A or less of] of p side contact layer to 200 A or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor layer to 500 A or less -- further -- resistivity -- it seems to be low -- since ****** is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0037]As mentioned above, in the nitride semiconductor device of this

Embodiment 1, as explained in full detail, since the 1st layer and 2nd layer constitute the p type clad layer 5 from laminated superlattice layers, this p type clad layer 5 is extremely made to low resistance, and Vf of this element can be made low.

[0038]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use p type superlattice layers not only for this but for the p side contact layer 6. That is, the p side contact layer 6 into which current (electron hole) is poured can also be made into the p type superlattice layers by which the 1st layer that consists of $In_XGa_{1-X}N$, and the 2nd layer that consists of $aluminum_YGa_{1-Y}N$ were laminated. When the p type contact layer 6 is made into superlattice layers and the bandgap energy of the 1st layer is smaller than the 2nd layer, It is preferred to consider it as the layer which bandgap energy makes the outermost surface the 1st layer that consists of small $In_XGa_{1-X}N$, and contacts p electrode, contact resistance with p electrode becomes small, and desirable OMIKKU is obtained by this. This is because the direction of the 1st layer with small bandgap energy is in the tendency for the nitride semiconductor layer whose carrier concentration is higher than the 2nd layer to be easy to be obtained. When forming further an above-mentioned p

side clad layer and p type nitride semiconductor layers other than p side contact layer in a p type nitride semiconductor layer field, superlattice layers may constitute this p type nitride semiconductor layer from this invention.

[0039]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use n type superlattice layers for the n side contact layer 3 of not only a p type nitride semiconductor layer field but a n type nitride semiconductor field. Thus, when making the n side contact layer 3 into superlattice layers, n type impurities, such as Si and germanium, can be doped in the 1st layer and/or 2nd layer, and the superlattice layers which have a n type conductivity type can be formed as the n type contact layer 3 between the substrate 1 and the active layer 4, for example. In this case, it was checked that it is in the tendency for lateral resistance to fall if especially the n type contact layer 3 is made into the superlattice layers which differ in impurity concentration, and for threshold voltage and current to fall in LD.

[0040]This about the case where the superlattice layers which doped many n type impurities are formed in the direction of the big layer of bandgap energy as a contact layer by the side of a n layer. The effect in which the operation similar to the following HEMT(s) (High-Electron-Mobility-Transistor) appeared is

guessed. The 1st layer with a large band gap by which the n type impurity was doped (the 2nd layer), A band gap in the superlattice layers which laminated the 2nd layer (the 1st layer) of small undoping {(undope) the state where the impurity is not doped below as for; is called undoping}. By the heterojunction interface of the layer which added the n type impurity, and a undoped layer, the big layer side of bandgap energy depletion-izes, and an electron (two dimensional electron gas) is accumulated in the interface before and behind the thickness (100 A) by the side of the small layer of bandgap energy. In order not to receive dispersion by an impurity when an electron runs since this two dimensional electron gas turns on the small layer side of bandgap energy, the degree of electron transfer of superlattice layers becomes high, and is guessed that resistivity falls.

[0041]In this invention, when providing the cladding layer by the side of n in a n type nitride semiconductor layer field, it is good also considering the cladding layer by the side of this n as superlattice layers. When forming n type nitride semiconductor layers other than n side contact layer and a n side clad layer in a n type nitride semiconductor layer field, it is good also considering this n type nitride semiconductor layer as superlattice layers. However, when providing the

nitride semiconductor layer which consists of superlattice layers in a n type nitride semiconductor layer field, it cannot be overemphasized that it is desirable to make into a superstructure the n side clad layer as a carrier confining layer or the n side contact layer 3 into which current (electron) is poured.

[0042]thus, when looking superlattice layers like [the n type nitride semiconductor layer field between the active layer 4 and the substrate 1] and providing them, it is not necessary to dope an impurity in the 1st layer and the 2nd layer which constitute superlattice layers It is because there is character which becomes a n type even when a nitride semiconductor is undoped. However, it is more desirable to dope n type impurities, such as Si and germanium, in the 1st layer and the 2nd layer, and to establish the difference of impurity concentration as mentioned above, when forming in the n layer side.

[0043]As mentioned above, crystalline improvement is mentioned like the case where the effect at the time of forming superlattice layers in a n type nitride semiconductor layer field provides superlattice layers in a p type nitride semiconductor layer field. When it explains in detail, in the case of the nitride semiconductor device which has a hetero-junction, the carrier confining layer of a n type and a p type usually comprises AlGaN with larger bandgap energy than

an active layer. Crystal growth is dramatically difficult for AlGaN, for example, when you are going to make it grow up by thickness of 0.5 micrometers or more with single composition, there is character in which a crack enters easily during a crystal. However, since a good crystalline thing will be obtained only in the 1st single layer and the 2nd layer if the 1st layer and the 2nd layer are laminated by the thickness below an elastic strain limit like this invention and it is superlattice layers, while crystallinity has been good also as thick superlattice layers of thickness, a cladding layer can grow the whole. Therefore, since the crystallinity of the whole nitride semiconductor becomes good and the mobility of a n type region becomes large, Vf falls with the element which made the superlattice layers the cladding layer. It seems that an effect similar to the above mentioned HEMT comes to show up notably when the impurity of Si and germanium is doped to superlattice layers and superlattice layers are made into a contact layer, and threshold voltage and Vf can be reduced further.

[0044]Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that

the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0045]Embodiment 2 concerning embodiment 2., next this invention is described. Drawing 2 is the structure of the nitride semiconductor device of Embodiment 2 concerning this invention a shown typical sectional view (section vertical to the resonant direction of a laser beam), and this nitride semiconductor device, For example, on the substrates 10, such as sapphire which makes C side a principal surface, A n type nitride semiconductor layer field. (it consists of the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15.) -- by a p type nitride semiconductor field (it consists of the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20.). It is the nitride semiconductor laser diode element provided with the active layer 16 which consists of a sandwiched nitride semiconductor.

[0046]Here the nitride semiconductor device of this Embodiment 2, The threshold voltage of the nitride semiconductor device which is an LD element is low set up by forming the n side clad layer 14 in a n type nitride semiconductor layer field by superlattice layers, and forming the p side clad layer 19 in a p type

nitride semiconductor field by superlattice layers. The nitride semiconductor device of Embodiment 2 which starts this invention with reference to this drawing 2 below is explained in detail.

[0047]In the nitride semiconductor device of this Embodiment 2, First, the n side contact layer 12 is formed via the buffer layer 11 and the 2nd buffer layer 112 on the substrate 10, further, on the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15 are laminated, and a n type nitride semiconductor layer field is formed. The n lateral electrode 23 which carries out ohmic contact to the n side contact layer 12 is formed in the surface of the n side contact layer 12 exposed to the both sides of the crack prevention layer 13, respectively, and the n side pad electrode for wire bonding is formed on these n lateral electrodes 23, for example. And the active layer 16 which consists of nitride semiconductors is formed on the n side light guide layer 15, further, on this active layer 16, the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20 are laminated, and a p type nitride semiconductor layer field is formed. The p lateral electrode 21 which carries out ohmic contact to these p side contact layers 20 is formed on the p side contact layer 20, and p side pad electrode for wire bonding

is formed on these p lateral electrodes 21, for example. By the upper part of the p side contact layer 20 and the p side clad layer 19. By the ridge part of the shape of Mine extended for a long time being constituted by the resonant direction, and forming this ridge part in it, In the active layer 16, light is shut up crosswise (direction which intersects perpendicularly with a resonant direction), and laser oscillation of the resonator which resonates to the longitudinal direction of a ridge part is produced and carried out using the cleavage plane by which cleavage was carried out in the direction vertical to a ridge part (electrode of stripe shape).

[0048]Next, each component of the nitride semiconductor device of Embodiment 2 is explained.

(Substrate 10) R side besides the sapphire which makes C side the substrate 10 with a principal surface, Semiconductor substrates, such as SiC (6H, 4H, and 3C are included), ZnS, ZnO, GaAs, GaN, etc. besides the sapphire which makes A side a principal surface, and other insulating substrates like a spinel ($MgA1_{2}O_{4}$), can be used.

[0049](Buffer layer 11) The buffer layer 11 grows up AlN, GaN, AlGaN, InGaN, etc. at the temperature of 900 ** or less, for example, and is formed in a

thickness number (10 A - hundreds of A). In order that this buffer layer 11 may ease the grating constant injustice of a substrate and a nitride semiconductor, it forms, but it is also possible to omit according to the growing method of a nitride semiconductor, the kind of substrate, etc.

[0050](The 2nd buffer layer 112) On said buffer layer 11, the 2nd buffer layer 112 is a layer which consists of a nitride semiconductor of the single crystal grown up at the elevated temperature rather than said buffer layer, and has a thick film rather than the buffer layer 11. the nitride semiconductor layer which this 2nd buffer layer 112 considers it as a layer with less n type impurity concentration than the n side contact layer 12 grown up into the next, or does not dope a n type impurity -- if it is a GaN layer preferably, the crystallinity of the 2nd buffer layer 112 will become good. If a n type impurity is most preferably set to undoped GaN, a nitride semiconductor with the most sufficient crystallinity will be obtained. If not less than several micrometers thickness tends to constitute n side contact layer which forms the negative electrode like before from the single nitride semiconductor layer of high carrier concentration, it is necessary to grow up a layer with large n type impurity concentration. As for the layer of a thick film with large impurity concentration, crystallinity tends to worsen. For this reason,

on a bad crystalline layer, even if it grows up other nitride semiconductors, such as an active layer, other layers will succeed a crystal defect and crystalline improvement cannot be expected. Then, before growing up 12 layers of n side contact layers, carrier concentration can grow up the good large crystalline n side contact layer 12 by growing up the 2nd good crystalline buffer layer 112 with small impurity concentration. As for the thickness of this 2nd buffer layer 112, it is still more preferably desirable most preferably to adjust to 1 micrometers or more and 20 micrometers or less 0.5 micrometers or more 0.1 micrometers or more. When the 2nd buffer layer 112 is thinner than 0.1 micrometer, the n type contact layer 12 with large impurity concentration must be grown up thickly, and it is in the tendency which can seldom expect crystalline improvement in the n side contact layer 12. When thicker than 20 micrometers, it is in the tendency for a crystal defect to increase easily in the 2nd buffer layer 112 the very thing. It is considered as the advantage into which the 2nd buffer layer 112 is grown up thickly, and improvement in heat dissipation nature is mentioned. That is, when a laser device is produced, the life of a laser device improves that heat spreads easily in the 2nd buffer layer 112. Furthermore, the light leaking of a laser beam spreads within the 2nd buffer layer 112, and it becomes easy to obtain the laser

beam near an ellipse form. The 2nd buffer layer 112 may be omitted when conductive substrates, such as GaN, SiC, and ZnO, are used for a substrate.

[0051](n side contact layer 12) The n side contact layer 12 is a layer which acts as a contact layer which forms the negative electrode, and it is desirable to adjust to 0.2 micrometers or more and 4 micrometers or less. If thinner than 0.2, when forming the negative electrode later, it is difficult to control an etching rate so that this layer may be exposed, and when not less than 4 micrometers is used, on the other hand, it is in the tendency for crystallinity to worsen under the influence of an impurity. The range of the n type impurity doped to the nitride semiconductor of this n side contact layer 12 The range of $1x10^{17}/cm^3$ - $1x10^{21}/cm^3$, It is desirable to adjust to $1x10^{18}/cm^3$ - $1x10^{19}/cm^3$ still more preferably. Since the material of n electrode and desirable OMIKKU will become is hard to be obtained if smaller than $1x10^{17}/cm^3$, In a laser device, a fall of a threshold current and voltage cannot be expected, but since the leakage current of the element itself will increase and crystallinity will also worsen if larger than $1x10^{21}/cm^3$, it is in the tendency for the life of an element to become short. In the n side contact layer 12, in order to make small ohmic contact resistance with the n electrode 23, it is desirable to make larger than the n cladding layer 14

concentration of the impurity which raises the carrier concentration of these n side contact layers 12. The n side contact layer 12 acts not as a contact layer but as a buffer layer, when providing the negative electrode in a substrate at the substrate rear side using conductive substrates, such as GaN, SiC, and ZnO.

[0052]At least one layer of the 2nd buffer layer 11 and the n side contact layers 12 can also be made into superlattice layers. If it is superlattice layers, the crystallinity of this layer will become good by leaps and bounds, and a threshold current will fall. Let the desirable n side contact layer 12 in which thickness is thinner than the 2nd buffer layer 11 be superlattice layers. In the case where the n side contact layer 12 is made into the superstructure which comes to laminate the 1st layer that differs in bandgap energy mutually, and the 2nd layer, By exposing the desirable small layer of bandgap energy and forming the n electrode 23, contact resistance with the n electrode 23 can be made low, and can reduce a threshold value. As a n type nitride semiconductor and a material of the n electrode 23 in which desirable OMIKKU is obtained, metal or alloys, such as aluminum, Ti, W, Si, Zn, Sn, and In, are mentioned.

[0053]By making the n type contact layer 12 into the superlattice layers which differ in impurity concentration, lateral resistance can be made low by an effect

similar to HEMT explained in Embodiment 1, and the threshold voltage of an LD element and current can be made low.

[0054](Crack prevention layer 13) The crack prevention layer 13 consists of $In_{0.1}Ga_{0.9}N$ which cm-^{3}[5x10 ^{18}/]-doped Si, for example, and has 500-A thickness, for example. This crack prevention layer 13 can prevent a crack from entering into the nitride semiconductor layer containing aluminum formed on it the n type nitride semiconductor containing In and by growing up InGaN preferably and forming. As for this crack prevention layer 13, it is preferred to make it grow up by 100 A or more and 0.5 micrometer or less of thickness. If thinner than 100 A, it will be hard to act as crack prevention as mentioned above, and when thicker than 0.5 micrometer, it is in the tendency for the crystal itself to be discolored in black. This crack prevention layer 13 may be omitted, when using the n side contact layer 12 as superlattice like this Embodiment 1, or when making into superlattice layers the n side clad layer 14 grown up into the next.

[0055](N side clad layer 14 which consists of n type superlattice) A n side clad layer, For example, it consists of n typeA10.2Ga0.8N which cm-^{3}[5x10 ^{18}/]-doped Si, The 1st layer that has 20-A thickness, and the 2nd layer that consists of undoped GaN and has 20-A thickness consist of superlattice layers

laminated by turns, and it has 0.5 micrometer of thickness on the whole. This n type clad layer 14 acts as a carrier confining layer and an optical confinement layer, The nitride semiconductor which contains aluminum for one of layers when it is considered as superlattice layers, It is desirable to grow up AlGaN preferably and 2 micrometers or less of 100 A or more can grow a good carrier confining layer by making it grow up at 500 A or more and 1 micrometer or less still more preferably. Although this n type clad layer 14 can also be grown up with a single nitride semiconductor, the good crystalline carrier confining layer where a crack does not have considering it as superlattice layers can be formed.

[0056](n side light guide layer 15) The n side light guide layer 15 consists of n type GaN which cm^{-3}[5x10 ^{18}/]-doped Si, for example, and has 0.1 micrometer of thickness. As for this n side light guide layer 6, it is desirable to act as a light guide layer of an active layer, to grow up GaN and InGaN, and to form, and it is usually desirable to make it grow up by 200 A - 1 micrometer of thickness still more preferably 100 A - 5 micrometers. This light guide layer 15 can also be made into superlattice layers. When making the n side light guide layer 15 and the n side clad layer 14 into superlattice layers, average bandgap energy of the nitride semiconductor layer which constitutes superlattice layers is made larger

than an active layer. When considering it as superlattice layers, a n type impurity may be doped in either [at least] the 1st layer or the 2nd layer, and undoping may be sufficient. The superlattice by which a undoped nitride semiconductor independent or a undoped nitride semiconductor was laminated may be sufficient as this light guide layer 15.

[0057](Active layer 16) The well layer which the active layer 16 consists of $In_{0.2}Ga_{0.8}N$ which doped Si by 8x10 ^{18}/cm^{3}, for example, and has 25-A thickness, It consists of $In_{0.05}1Ga_{0.95}N$ which cm-^{3}[8x10 ^{18}/]-doped Si, and constitutes from multiple quantum well structure (MQW) which has predetermined thickness by laminating by turns the barrier layer which has 50-A thickness. In the active layer 16, an impurity may be doped to both a well layer and a barrier layer, and it may dope to either. When a n type impurity is doped, it is in the tendency for a threshold value to fall. Superlattice layers are distinguished in order to certainly laminate the small well layer of bandgap energy, and the barrier layer in which bandgap energy is smaller than a well layer, in making the active layer 16 into multiple quantum well structure in this way. 100 A or less of thickness [70 A or less of] of a well layer shall be 50 A or less most preferably. 150 A or less of thickness [100 A or less of] of a barrier layer shall be 70 A or less most

preferably.

[0058](p side cap layer 17) Rather than the active layer 16, bandgap energy is large, for example, consists of p type aluminum$_{0.3}$Ga$_{0.7}$N which cm-^{3}[1x10 ^{20}/]-doped Mg, and the p side cap layer 17 has 200-A thickness, for example. Although it is preferred in this Embodiment 2 to use the cap layer 17 in this way, since this cap layer is formed in thin thickness, it is good also as an i type which doped the n type impurity and with which the carrier was compensated by this invention. 0.1 micrometer or less of thickness [500 A or less of] of the p side cap layer 17 is most preferably adjusted to 300 A or less still more preferably. It is because a crack enters easily into the p side cap layer 17 and a good crystalline nitride semiconductor layer cannot grow easily, if it is made to grow up by thickness thicker than 0.1 micrometer. It is because it becomes impossible to pass the p type capping layer 17 from which a carrier becomes that the thickness of the p side cap layer 17 is 0.1 micrometers or more with this energy barrier according to the tunnel effect, When passage of the carrier by this tunnel effect is taken into consideration, it is preferred to set it as 500 A or less and 300 more A or less to have mentioned above.

[0059]To the p side cap layer 17, in order to make an LD element easy to

oscillate, it is preferred that the composition ratio of aluminum uses and forms large AlGaN, and it becomes easy to oscillate an LD element, so that this AlGaN is formed thinly. For example, if Y value is 0.2 or more $aluminum_YGa_{1-Y}N$, adjusting to 500 A or less is desirable. Although the minimum in particular of the thickness of the p side cap layer 17 does not limit, it is desirable to form by thickness of 10 A or more.

[0060](p side light guide layer 18) Bandgap energy is smaller than the p side cap layer 17, for example, consists of p type GaN which cm^{-3}[$1x10^{20}$/]-doped Mg, and the p side light guide layer 18 has 0.1 micrometer of thickness. As for this p side light guide layer 18, it is desirable to act as a light guide layer of the active layer 16, to make it grow up by GaN and InGaN as well as the n side light guide layer 15, and to form. This layer acts as a desirable light guide layer by acting also as a buffer layer at the time of growing up the p side clad layer 19, and growing up 100 A - 5 micrometers by 200 A - 1 micrometer of thickness still more preferably. Although this p side light guide layer usually dopes p type impurities, such as Mg, and considers it as a p type conductivity type, it is not necessary to dope an impurity in particular. This p side light guide layer can also be made into superlattice layers. When considering it as superlattice layers, a p type impurity

may be doped in either [at least] the 1st layer or the 2nd layer, and undoping may be sufficient.

[0061](P side clad layer 19= superlattice layers) The p side clad layer 19, For example, the 1st layer that consists of p type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg, and has 20-A thickness, for example, For example, it consists of p type GaN which cm^{-3}[1x10 ^{20}/]-doped Mg, and the 2nd layer that has 20-A thickness consists of superlattice layers laminated by turns. This p side clad layer 19 acts as a carrier confining layer as well as the n side clad layer 14, and acts as a layer for reducing especially resistivity of a p type layer. Although thickness in particular of this p side clad layer 19 is not limited, either, it is desirable to form at 500 A or more and 1 micrometer or less still more preferably 2 micrometers or less 100 A or more.

[0062](p side contact layer 20) On the p side clad layer 19, the p side contact layer 20 consists of p type GaN which cm^{-3}[2x10 ^{20}/]-doped Mg, for example, and has 150-A thickness, for example. This p side contact layer 20 can be constituted from p type $In_XAl_YGa_{1-X-Y}N$ (0<=X, 0<=Y, X+Y<=1), and if referred to as GaN which doped Mg as mentioned above preferably, the p electrode 21 and the most desirable ohmic contact will be obtained. It is desirable to adjust still

more preferably 500 A or less of thickness [300 A or less of] of p side contact layer to 200 A or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts thickness of a certain p type nitride semiconductor layer to 500 A or less -- further -- resistivity -- it seems to be low -- since ****** is made, current in a threshold value and voltage fall. Quantity of hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0063]The p side contact layer 20 can also be made into superlattice layers in this invention. Especially in considering it as superlattice layers, it laminates the 1st layer and 2nd layer that differ in bandgap energy, the -- the [1+] -- the [2+] -- 1+ the 2+ ... as -- if it laminates and is finally made exposed [a layer with smaller bandgap energy], the p electrode 21 and desirable ohmic contact will be obtained. As a material of the p electrode 21, nickel, Pd, nickel/Au, etc. can be mentioned, for example.

[0064]The insulator layer 25 which consists of SiO_2 is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23 in this Embodiment 2 as shown in drawing 2, The p pad electrode 22 electrically connected with the p electrode 21 via an opening formed in this

insulator layer 25 and the n pad electrode 24 connected with the n electrode 23 are formed. this p pad electrode 22 extends surface area of the substantial p electrode 21 -- the p electrode side -- wire bonding -- being able to be made to carry out die bonding, on the other hand, the n pad electrode 24 prevents peeling of the n electrode 23.

[0065]The nitride semiconductor device of above Embodiment 2 is provided with the good crystalline p type clad layer 19 which is the superlattice layers which made the 1st layer and the 2nd layer the thickness below an elastic strain limit, and were laminated. By this, since the nitride semiconductor device of this Embodiment 2 can make low the single or more figures resistance of the p side clad layer 19 as compared with the p side clad layer which does not have a superstructure, it can make threshold voltage and current low.

[0066]The p side clad layer 19 which contains p type aluminum$_Y$Ga$_{1-Y}$N in the nitride semiconductor device of this Embodiment 2 is touched, By forming the thickness thinly with 500 A or less by making the small nitride semiconductor of bandgap energy into the p side contact layer 20, The carrier concentration of the p side contact layer 20 becomes high substantially, p electrode and desirable OMIKKU are obtained, and the threshold current of an element and voltage can

be made low. Since it has the 2nd buffer layer 112 before growing up n side contact layer, the crystallinity of the nitride semiconductor layer grown up on the 2nd buffer layer 112 becomes good, and a long lasting element can be realized. If n side contact layer grown up on the 2nd buffer layer 112 is preferably used as superlattice, lateral resistance becomes low and the low element of threshold voltage and a threshold current can be realized.

[0067]In equipping the active layer 16 with a nitride semiconductor like InGaN which contains indium at least in the LD element of this Embodiment 2, It is preferred that $In_XGa_{1-X}N$ and $aluminum_YGa_{1-Y}N$ use the superlattice layers laminated by turns as a layer (the n side clad layer 14 and the p side clad layer 19) which sandwiches the active layer 16. By this, since the bandgap energy difference of the active layer 16 and these superlattice layers and refractive index difference can be enlarged, these superlattice layers can be operated as a dramatically outstanding optical confinement layer, when realizing a laser device. Since InGaN is [the character of a crystal] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. The life of an LD element can be lengthened

by this.

[0068]In the case of the semiconductor device of the double hetero structure of having the active layer 16 which has quantum well structure like this Embodiment 2, the active layer 16 is touched, The p side cap layer 17 which consists of a nitride semiconductor of 0.1 micrometer or less of thickness with larger bandgap energy than the active layer 16, and the p side cap layer 17 which consists of a nitride semiconductor which contains aluminum preferably are formed, The p side light guide layer 18 in which bandgap energy is smaller than the p side cap layer 17 is formed in the position which is separated from an active layer rather than the p side cap layer 17, It is dramatically more preferred than the p side light guide layer 18 to form the p side clad layer 19 which has a superstructure which contains a nitride semiconductor with a larger band gap than the p side light guide layer 18 and the nitride semiconductor which contains aluminum preferably in the position which is separated from an active layer. And in order that the electron poured in from the n layer since bandgap energy of the p side cap layer 17 was enlarged may be prevented by this p side cap layer 17, and may be shut up and an electron may not overflow an active layer, the leakage current of an element decreases.

[0069]Although the nitride semiconductor device of above Embodiment 2 showed a structure desirable as a structure of a laser device, What is necessary is just to have at least one layer of n type superlattice layers from the active layer 16 in this invention to the lower n type nitride semiconductor layer field (n type layer side), What is necessary is just to also have at least one layer of p type superlattice layers from the active layer 16 to the upper p type nitride semiconductor layer field (p type layer side), and element composition in particular is not specified. However, said superlattice layers are formed in the p side clad layer 19 as a carrier confining layer when forming in the p layer side, When forming in the n layer side and forming as the n contact layer 12 as a current injection layer which the n electrode 23 touched, or the n cladding layer 14 as carrier ****** reduces Vf of an element, and a threshold value, it is in the most desirable tendency. It cannot be overemphasized that the same composition as the element of Embodiment 2 is applicable to a LED element (however, in a LED element, a ridge part is unnecessary).

[0070]In the nitride semiconductor device of Embodiment 2 constituted as mentioned above. In the atmosphere which does not contain H, for example, a nitrogen atmosphere, after each layer is formed, It is preferred to perform

annealing, for example at 700 ** not less than 400 **, and since each layer of a p type nitride semiconductor layer field can be further low-resistance-ized by this, threshold voltage can be further made low by this.

[0071]In the nitride semiconductor device of Embodiment 2, the p electrode 21 which becomes the surface of the p side contact layer 12 from nickel and Au was formed in stripe shape, n side contact layer was symmetrically exposed to this p electrode 21, and the n electrode 23 is formed all over almost [of that n side contact layer surface]. Thus, when the structure of forming the n electrode 23 symmetrically with the both sides of the p electrode 21 when an insulating substrate is used makes threshold voltage low, it is dramatically advantageous.

[0072]In this Embodiment 2, the dielectric multilayer which consists of SiO_2 and TiO_2 may be formed in the cleavage plane (resonator face) which carried out cleavage in the direction vertical to a ridge part (electrode of stripe shape).

[0073]Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that

the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

EXAMPLE

[Working example]Hereafter, in working example, this invention is explained in full detail.

[Working example 1] Working example 1 concerning this invention is an example of creation of the nitride semiconductor device (LD element) shown in drawing 2, and is produced in the following procedures. First, passing hydrogen, after setting the substrate 10 which consists of sapphire (C side) in a reaction vessel and replacing the inside of a container enough from hydrogen, the temperature of a substrate is raised to 1050 ** and a substrate is cleaned. Then, temperature is lowered to 510 **, hydrogen is used for carrier gas, ammonia (NH_3) and TMG (trimethylgallium) are used for material gas, and the 1st buffer layer 11 that comes from GaN on the substrate 10 is grown up by about 200-A thickness.

[0075]Only TMG is stopped after buffer layer 11 growth, and temperature is raised to 1050 **. If it becomes 1050 **, similarly TMG and ammonia gas will be used for material gas, and the 2nd buffer layer 112 that consists of the undoping

GaN of carrier concentration 1x10 ^{18}/cm^{3} will be grown up by 5-micrometer thickness. the 2nd buffer layer -- $In_XAl_YGa_{1-X-Y}N$ (0<=X.) Although it can constitute from 0<=Y and X+Y<=1 and the presentation in particular is not asked, it is preferably undoped and aluminum (Y value) sets to 0.1 or less aluminum$_{Y}$Ga$_{1-Y}$N and most desirable undoped GaN. Then, silane gas (SiH_4) is used for TMG, ammonia, and impurity gas at 1050 **, and the n side contact layer 12 which consists of n type GaN which cm-^{3}[1x10 ^{19}/]-doped Si is grown up by 1 micrometer of thickness. When this n side contact layer 12 is formed by superlattice, it is still more preferred.

[0076]Temperature shall be 800 ** and to material gas Next, TMG, TMI (trimethylindium), Silane gas is used for ammonia and impurity gas, and the crack prevention layer 13 which consists of $In_{0.1}Ga_{0.9}N$ which cm--^{3}[5x10 ^{18}/]-doped Si is grown up by 500-A thickness. And temperature shall be 1050 ** and TMA, TMG, ammonia, and silane gas are used, The 1st layer that consists of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm-^{3}[5x10 ^{18}/]-doped Si is grown up by 20-A thickness, then TMA and Silang are stopped and the 2nd layer that consists of the undoping GaN is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the n side clad layer 14 which consists of

superlattice layers of 0.4 micrometer of the total thickness is grown up.

[0077]Then, the n side light guide layer 15 which consists of n type GaN which cm^{-3}[5x10 ^{18}/]-doped Si at 1050 ** is grown up by 0.1 micrometer of thickness. Next, the active layer 16 is grown up using TMG, TMI, ammonia, and Silang. The active layer 16 holds temperature at 800 **, and grows up the well layer which consists of $In_{0.2}Ga_{0.8}N$ which doped Si by 8x10 $^{18}/cm^3$ first by 25-A thickness. Next, the barrier layer which consists of $In_{0.01}Ga_{0.99}N$ which cm^{-3}[8x10 ^{18}/]-doped Si at the same temperature only by changing the mole ratio of TMI is grown up by 50-A thickness. This operation is repeated twice and the active layer 16 of the multiple quantum well structure (MQW) of 175 A of the total thickness that finally laminated the well layer is grown up.

[0078]Raise temperature to 1050 ** and to material gas Next, TMG, TMA, ammonia, Cp_2Mg (magnesium cyclopentadienyl) is used for impurity gas, The p side cap layer 17 which consists of p type $aluminum_{0.3}Ga_{0.7}N$ in which bandgap energy was large and cm^{-3}[1x10 ^{20}/]-doped Mg rather than the active layer is grown up by 300-A thickness. Then, the p side light guide layer 18 which bandgap energy becomes at 1050 ** from p type GaN smaller than the p side cap layer 17 to which Mg was cm^{-3}[1x10 ^{20}/]-doped is grown up by 0.1

micrometer of thickness.

[0079]Then, TMA, TMG, ammonia, and Cp_2Mg are used, The 1st layer that consists of p type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[1x10 ^{20}/]-doped Mg at 1050 ** is grown up by 20-A thickness, Then, only TMA is stopped and the 2nd layer that consists of p type GaN which cm^{-3}[1x10 ^{20}/]-doped Mg is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness is formed. The p side contact layer 20 which finally consists of p type GaN which cm-$^{-3}$[2x10 ^{20}/]-doped Mg on the p side clad layer 19 at 1050 ** is grown up by 150-A thickness.

[0080]Temperature is lowered to a room temperature after ending reaction, among a nitrogen atmosphere, in a reaction vessel for a wafer, annealing is performed at 700 ** and a p type layer is low-resistance-ized further. As a wafer is picked out from a reaction vessel after annealing and it is shown in drawing 2, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has the stripe width of 4 micrometers.

[0081]Next, as a mask is formed in the ridge surface and it is shown in drawing 2,

it is made symmetrical to the ridge of stripe shape, and the surface of the n side contact layer 12 is exposed. Next, the p electrode 21 which consists of nickel and Au all over almost [of the stripe ridge outermost surface of the p side contact layer 20] is formed. On the other hand, the n electrode 23 which consists of Ti and aluminum is formed all over almost [of the n side contact layer 3 of stripe shape].

[0082]Next, as shown in drawing 2, the insulator layer 25 which consists of SiO_2 is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23, and the p pad electrode 22 electrically connected with the p electrode 21 via this insulator layer 25 and the n pad electrode 24 are formed. A wafer which formed n electrode and p electrode as mentioned above shall be transported to polish equipment, the silicon on sapphire 1 of a side which does not form a nitride semiconductor shall be wrapped using a diamond polishing agent, and thickness of a substrate shall be 50 micrometers. After wrapping, 1 micrometer is polished with still finer abrasive soap, and a substrate face is made into mirror finished surface form.

[0083]The scribe after substrate polish and of the polished surface side is carried out, cleavage is carried out to bar shape in a direction vertical to an electrode of

stripe shape, and a resonator is produced to a cleavage plane. A dielectric multilayer which consists of SiO_2 and TiO_2 was formed in a resonator face, and finally, in a direction parallel to p electrode, Bar was cut and it was considered as a laser chip. Next, in [when a chip was installed in a heat sink by face up (state which a substrate and a heat sink countered), wire bonding of each electrode was carried out and laser oscillation was tried at a room temperature] a room temperature, With threshold current density 2.9 kA/cm^2 and the threshold voltage 4.4V, continuous oscillation with an oscillation wavelength of 405 nm was checked, and a life of 50 hours or more was shown.

[0084](Comparative example 1) n type GaN which did not grow up the 2nd buffer layer 112 and cm^{-3}[1x10 ^{19}/]-doped Si for the n side contact layer 12 further on the other hand -- it being single, and 5 micrometers being grown up, and, 0.4 micrometer of n side clad layers 14 are grown up by a n type $aluminum_{0.2}Ga_{0.8}N$ single which cm^{-3}[1x10 ^{19}/]-doped Si, 0.4 micrometer of p side clad layers 19 are grown up by a p type $aluminum_{0.2}Ga_{0.8}N$ single which 1-x-10-^{20}-/-m-^{3}-doped Mg, 0.2 micrometer of single p type GaN(s) which furthermore cm^{-3}[2x10 ^{20}/]-doped Mg for the p side contact layer 20 were grown up, and also a laser device was obtained like working example 1. That is, as basic constitution, as shown in

Table 1, it constitutes.

[0085]

[Table 1]

基板	10・・・サファイア	
バッファ層	11・・・GaN	200Å
nコンタクト層	12・・・Siドープn型GaN Si:1×10^{19}/cm^3	5μm
クラック防止層	13・・・Siドープn型In0.1Ga0.9N Si:5×10^{18}/cm^3	500Å
nクラッド層	14・・・Siドープn型Al0.2Ga0.8N Si:5×10^{18}/cm^3	0.5μm
n光ガイド層	15・・・Siドープn型GaN Si:5×10^{18}/cm^3	0.1μm
活性層(MQW) (総膜厚175Å)	16・・・SiドープIn0.2Ga0.8N SiドープIn0.01Ga0.95N Si:8×10^{18}/cm^3	25Å 50Å
キャップ層	17・・・Mgドープp型Al0.1Ga0.9N Mg:1×10^{20}/cm^3	300Å
p光ガイド層	18・・・Mgドープp型GaN Mg:1×10^{20}/cm^3	0.1μm
pクラッド層	19・・・Mgドープp型Al0.2Ga0.8N Mg:1×10^{20}/cm^3	0.5μm
pコンタクト層	20・・・Mgドープp型GaN Mg:2×10^{20}/cm^3	0.2μm

[0086]Although continuous oscillation was checked by threshold current density 7 kA/cm^2 as for a laser device of a comparative example constituted in this way, threshold voltage has gone out in those or more [8.0] with V, and several minutes.

[0087][Working example 2] The 1st layer that consists the n side contact layer 12 of n type aluminum$_{0.05}$Ga$_{0.95}$N which cm^{-3}[2x10 ^{19}/]-doped Si in working example

1 is grown up by 30-A thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 30-A thickness, this is repeated, and it is considered as the superstructure of 1.2 micrometers of the total thickness. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 2.7 kA/cm^2 and the threshold voltage 4.2V, and, as for the other structure, the life also showed 60 hours or more.

[0088][Working example 3] In working example 2, set the 2nd layer to GaN which cm^{-3}[$1x10^{18}$/]-doped Si in the superlattice which constitutes the n side contact layer 12, and also. When the laser device which has the same structure as working example 2 was produced, the laser device which has the characteristic almost equivalent to working example 2 was obtained.

[0089][Working example 4] In working example 1, set the 2nd buffer layer 112 to GaN which cm^{-3}[$1x10^{17}$/]-doped Si, and grow up it 4 micrometers, and also. When the laser device which has the same structure as working example 1 was produced, it went up to threshold current density 2.9 kA/cm^2 and the threshold voltage 4.5V, but the life showed 50 hours or more.

[0090][Working example 5] The 1st layer that consists the n side contact layer 12 of n type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[$2x10^{19}$/]-doped Si in working example 1

is grown up by 60-A thickness, Then, the 2nd layer that consists of GaN which cm^{-3}[1x10 ^{19}/]-doped Si is grown up by 40-A thickness, this is repeated successively, and it is considered as the superstructure of 2 micrometers of the total thickness. And 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum$_{0.2}$Ga$_{0.8}$N single which cm^{-3}[1x10 ^{19}/]-doped Si. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 3.2 kA/cm^2 and the threshold voltage 4.8V, and, as for the other structure, the life also showed 30 hours or more.

[0091][Working example 6] As compared with working example 1, following (1) differs from (2), and also working example 6 is constituted like working example 1.

(1) Stop only TMG after buffer layer 11 growth, and raise temperature to 1050 **. If it becomes 1050 **, TMA, TMG, ammonia, and Silang will be used for material gas, The 1st layer that consists of n type aluminum$_{0.2}$Ga$_{0.8}$N which cm^{-3}[1x10 ^{19}/]-doped Si is grown up by 60-A thickness, then Silang and the 2nd layer that stops TMA and consists of undoped GaN are grown up by 40-A thickness. and 1st layer + 2nd layer + 1st layer + 2nd layer + ... as -- superlattice layers are constituted, respectively the 1st layer is laminated to 500 layers, the 2nd layer is

laminated alternately [500 layer], and the n side contact layer 12 which consists of superlattice of 5 micrometers of the total thickness is formed.

(2) Next, grow up the crack prevention layer 13 which consists of $In_{0.1}Ga_{0.9}N$ which cm^{-3}[5x10 ^{18}/]-doped Si like working example 1 by 500-A thickness. And temperature shall be 1050 ** and the n side clad layer 14 which consists of n type $aluminum_{0.2}Ga_{0.8}N$ which cm^{-3}[5x10 ^{18}/]-doped Si is grown up by 0.5 micrometer of thickness using TMA, TMG, ammonia, and Silang. Let tops be a laser device of working example 1, and a laser device which has the same structure from the next n side clad layer 14. That is, in the basic structure of Table 1, the n side contact layer 12 and the p side clad layer 19 are used as superlattice, and the laser device which makes 150 A thickness of the p side contact layer 20 like working example 1 is produced. This laser device was threshold current density 3.2 kA/cm^2 and the threshold voltage 4.8V, 405-nm continuous oscillation was checked and the life also showed 30 hours or more.

[0092]When the thickness of p side contact layer of the LD element of the structure of working example 6 is changed one by one, the relation between the thickness of the p side contact layer and the threshold voltage of an LD element

is shown in drawing 3. As for this, p side contact layers are A (10 A or less), B (10 A), C (30 A), and D from the left to order.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1]It is a type section figure showing the composition of the nitride semiconductor device (LED element) of Embodiment 1 concerning this invention.

[Drawing 2]It is a type section figure showing the composition of the nitride semiconductor device (LD element) of Embodiment 2 concerning this invention.

[Drawing 3]It is a graph which shows the thickness of p side contact layer in the LD element of working example 1 concerning this invention, and a relation with threshold voltage.

[Drawing 4]It is a type section figure of the LD element of working example 26 concerning this invention.

[Explanations of letters or numerals]

1, 10 .... Substrate,

2, 11 .... Buffer layer

3, 12 .... n side contact layer,

13 .... Crack prevention layer,

14 .... N side clad layer (superlattice layers),

15 .... The n side light guide layer,

4, 16 .... Active layer,

17 .... Cap layer

18 .... The p side light guide layer,

5, 19 .... P side clad layer (superlattice layers),

6, 20 .... p side contact layer,

7, 21 .... p electrode,

8, 22 .... p pad electrode,

9, 23 .... n electrode,

24 .... n pad electrode,

25 .... Insulator layer,

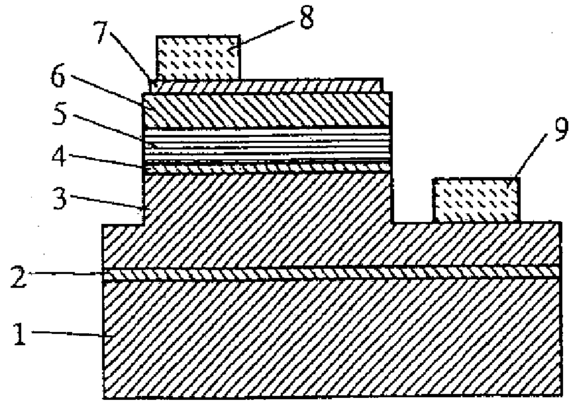
101 .... GaN board,

112 .... The 2nd buffer layer,

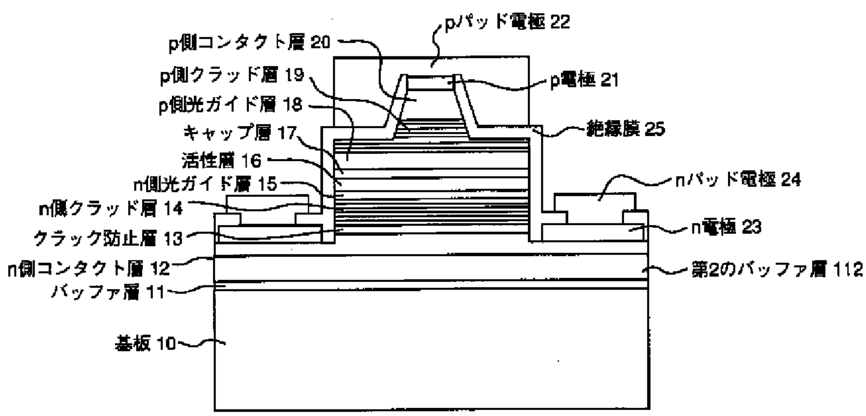
113 .... The 3rd buffer layer.

DRAWINGS

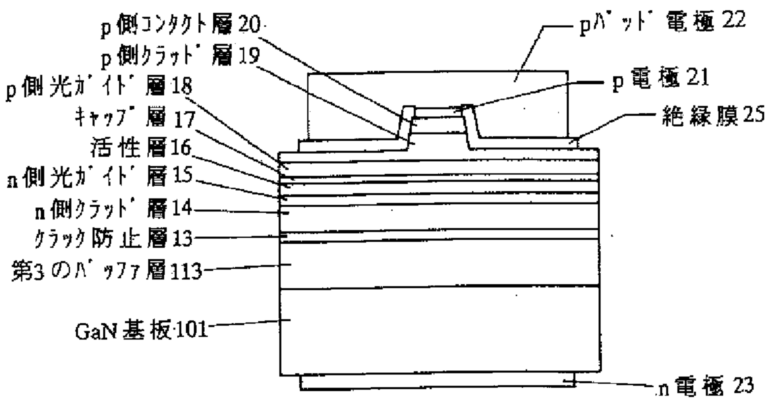
[Drawing 1]



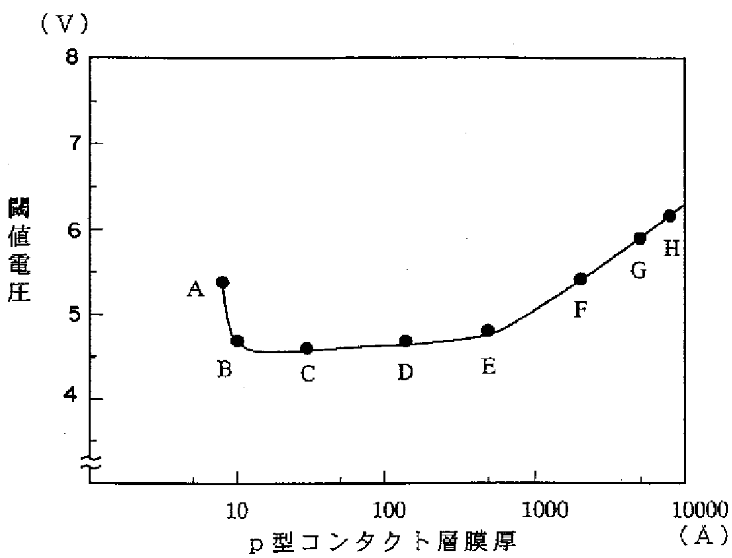
[Drawing 2]



[Drawing 4]


p側ｺﾝﾀｸﾄ層20
p側ｸﾗｯﾄﾞ層19
p側光ｶﾞｲﾄﾞ層18
ｷｬｯﾌﾟ層17
活性層16
n側光ｶﾞｲﾄﾞ層15
n側ｸﾗｯﾄﾞ層14
ｸﾗｯｸ防止層13
第3のﾊﾞｯﾌｧ層113
GaN基板101
pﾊﾟｯﾄﾞ電極22
p電極21
絶縁膜25
n電極23

[Drawing 3]


(V)
8
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6
5
4
閾値電圧
A
B
C
D
E
F
G
H
10
100
1000
10000
(Å)
p型コンタクト層膜厚

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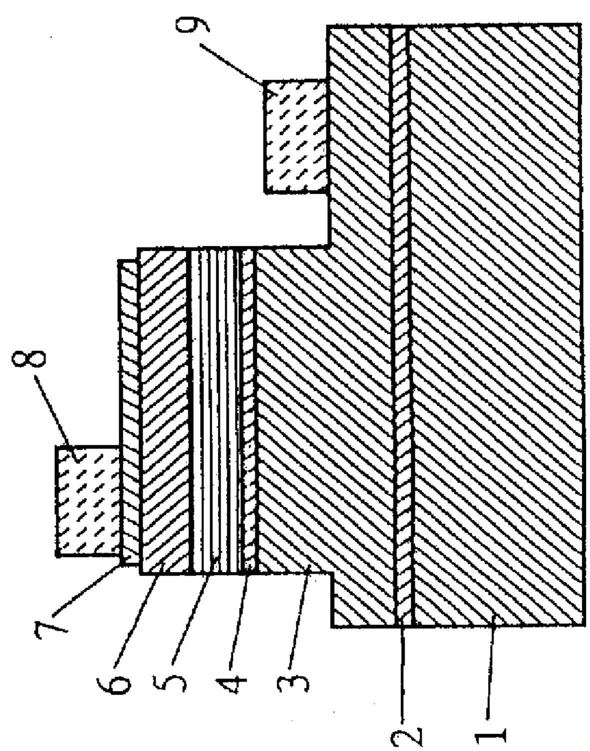
最終頁に続く

(54)【発明の名称】　窒化物半導体素子

(57)【要約】
【課題】　電力効率のよい窒化物半導体素子を提供する。
【解決手段】　基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、ｎ側光ガイド層上に形成された窒化物半導体からなる活性層と、その活性層上に形成された、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有し、ｐ側クラッド層を、１０オングストローム以上で１００オングストローム以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０オングストローム以上で１００オングストローム以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層とした。



【特許請求の範囲】

【請求項１】　基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記ｐ側クラッド層は、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項２】　前記第１の層及び前記第２の層の内の少なくとも一方に、ｐ型不純物がドープされた請求項１記載の窒化物半導体素子。

【請求項３】　前記第１の層及び前記第２の層にドープされたｐ型不純物の濃度が互いに異なる請求項２記載の窒化物半導体素子。

【請求項４】　前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項２又は３記載の窒化物半導体素子。

【請求項５】　基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記ｐ側クラッド層及び前記ｎ側クラッド層のうち少なくとも一つは、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項６】　前記ｐ側クラッド層が前記超格子層であり、前記第１の層及び前記第２の層の内の少なくとも一方に、ｐ型不純物がドープされた請求項５の窒化物半導体素子。

【請求項７】　前記第１の層及び前記第２の層にドープされたｐ型不純物の濃度が互いに異なる請求項６記載の窒化物半導体素子。

【請求項８】　前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項７記載の窒化物半導体素子。

【請求項９】　前記ｎ側クラッド層が前記超格子層であり、前記第１の層及び前記第２の層の内の少なくとも一方に、ｎ型不純物がドープされた請求項５の窒化物半導体素子。

【請求項１０】　前記第１の層及び前記第２の層にドープされたｎ型不純物の濃度が互いに異なる請求項９記載の窒化物半導体素子。

【請求項１１】　前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項１０記載の窒化物半導体素子。

【請求項１２】　前記第２の層が、式$Al_Y Ga_{1-Y} N$（ただし、$0<Y\leqq 1$）であらわされる窒化物半導体である請求項１～１１に記載の窒化物半導体素子。

【請求項１３】　前記超格子層において、前記第１の層が式$In_X Ga_{1-X} N$（$0\leqq X\leqq 1$）で表される窒化物半導体からなり、かつ前記第２の層が式$Al_Y Ga_{1-Y} N$（ただし、$0<Y\leqq 1$）で表される窒化物半導体からなる請求項１２に記載の窒化物半導体素子。

【請求項１４】　前記超格子層において、前記第１の層が式$In_X Ga_{1-X} N$（$0\leqq X<1$）で表される窒化物半導体からなり、かつ前記第２の層が式$Al_Y Ga_{1-Y} N$（ただし、$0<Y<1$）で表される窒化物半導体からなる請求項１３に記載の窒化物半導体素子。

【請求項１５】　前記第１の層及び前記第２の層がそれぞれ、７０Å以下の膜厚を有する窒化物半導体からなる請求項１～１４のうちのいずれか１項に記載の窒化物半導体素子。

【請求項１６】　前記ｐ側コンタクト層の膜厚が５００Å以下である請求項１～１５のうちのいずれか１項に記載の窒化物半導体素子。

【請求項１７】　前記ｐ側コンタクト層の膜厚がさらに、３００Å以下、１０Å以上である請求項１６記載の窒化物半導体素子。

【請求項１８】　基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記ｎ側クラッド層が、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であり、かつ前記ｐ側クラッド層が、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第３の層と、該第３の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第４の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項１９】　前記ｐ側クラッド層及び該ｐ側クラッド層より上に形成されている層において、共振方向に峰

状のリッジ部が形成された請求項１８記載の窒化物半導体素子。

【請求項２０】　前記活性層は、インジウムを含む窒化物半導体を有する請求項１～１９のうちのいずれか１項に記載の窒化物半導体素子。

【請求項２１】　前記窒化物半導体素子が、サファイア基板のＣ面上に形成されている請求項１～２０のうちいずれか１項に記載の窒化物半導体素子。

【請求項２２】　前記窒化物半導体素子が、サファイア基板のＣ面上にＳｉをドープしたＧａＮ層を成長させた後、サファイア基板を除去したＧａＮ基板上に形成されている請求項１～２０のうちいずれか１項に記載の窒化物半導体素子。

【請求項２３】　前記ｎ側光ガイド層はＧａＮある請求項１～２２のうちいずれか１項に記載の窒化物半導体素子。

【請求項２４】　前記ｎ側光ガイド層はＩｎＧａＮである請求項１～２２のうちいずれか１項に記載の窒化物半導体素子。

【請求項２５】　前記ｐ側光ガイド層はＧａＮである請求項１～２４のうちいずれか１項に記載の窒化物半導体素子。

【請求項２６】　前記ｐ側光ガイド層はＩｎＧａＮである請求項１～２４のうちいずれか１項に記載の窒化物半導体素子。

【請求項２７】　前記窒化物半導体素子は、前記活性層に接して、Ａｌを含む窒化物半導体よりなるｐ側キャップ層を有し、そのｐ側キャップ層よりも活性層から離れた位置に、前記ｐ側キャップ層よりもバンドギャップエネルギーが小さいｐ側光ガイド層を有する請求項１～２６のうちいずれか１項に記載の窒化物半導体素子。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明はＬＥＤ（発光ダイオード）、ＬＤ（レーザダイオード）等の発光素子、太陽電池、光センサー等の受光素子、又はトランジスタ等の電子デバイスに使用される窒化物半導体（$In_{X}Al_{Y}Ga_{1-X-Y}N$、０≦Ｘ、０≦Ｙ、Ｘ＋Ｙ≦１）よりなる素子に関する。なお、本明細書において使用する一般式$In_{X}Ga_{1-X}N$、$Al_{Y}Ga_{1-Y}N$等は単に窒化物半導体層の組成式を示すものであって、異なる層が例えば同一の一般式で示されていても、それらの層のＸ値、Ｙ値が一致していることまで示すものではない。

【０００２】

【従来の技術】窒化物半導体は高輝度青色ＬＥＤ、純緑色ＬＥＤの材料として、フルカラーＬＥＤディスプレイ、交通信号等で最近実用化されたばかりである。これらの各種デバイスに使用されるＬＥＤは、ｎ型窒化物半導体層とｐ型窒化物半導体層との間に、単一量子井戸構造（ＳＱＷ：Single-Quantum- Well）のＩｎＧａＮよりなる活性層が挟まれたダブルヘテロ構造を有している。青色、緑色等の波長はＩｎＧａＮ活性層のＩｎ組成比を増減することで決定されている。

【０００３】また、本出願人は、最近この材料を用いてパルス電流下、室温での４１０ｎｍのレーザ発振を世界で初めて発表した（例えば、Jpn.J.Appl.Phys. Vol35 (1996) pp.L74-76）。このレーザ素子はパルス幅２μｓ、パルス周期２ｍｓの条件で、閾値電流６１０ｍＡ、閾値電流密度８．７ｋＡ／cm^2、４１０ｎｍの発振を示す。さらにまた、閾値電流が低い改良したレーザ素子を、Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, p.1477-1479において発表した。このレーザ素子は、ｐ型窒化物半導体層の一部にリッジストライプが形成された構造を有しており、パルス幅１μｓ、パルス周期１ｍｓ、デューティー比０．１％で、閾値電流１８７ｍＡ、閾値電流密度３ｋＡ／cm^2、４１０ｎｍの発振を示す。

【０００４】

【発明が解決しようとする課題】窒化物半導体よりなる青色、緑色ＬＥＤは順方向電流（Ｉｆ）２０ｍＡで、順方向電圧（Ｖｆ）が３．４Ｖ～３．６Ｖあり、ＧａＡｌＡｓ系の半導体よりなる赤色ＬＥＤに比べて２Ｖ以上高いため、さらなるＶｆの低下が望まれている。また、ＬＤでは閾値での電流、電圧が未だ高く、室温で連続発振させるためには、この閾値電流、電圧が下がるような、さらに電力効率の高い素子を実現する必要がある。

【０００５】従って本発明の目的とするところは、主として窒化物半導体よりなるＬＤ素子の閾値での電流、電圧を低下させることにより連続発振を実現し、またＬＥＤ素子ではＶｆを低下させ、信頼性が高く、電力効率に優れた窒化物半導体素子を実現することにある。

【０００６】

【課題を解決するための手段】本発明者らは、窒化物半導体素子について、活性層を挟んだｐ型層、及び／又はｎ型層を改良すべく鋭意検討した結果、活性層を除くｐ型層、及び／又はｎ型層に超格子層を用いることにより、超格子層を用いた層の結晶性を良好にでき、前記問題を解決できることを新たに見いだし本発明を成すに至った。

【０００７】すなわち、本発明に係る第１の窒化物半導体素子は、基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、前記ｐ側クラッド層は、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であることを特徴とする。これによって、前記超格子層からなるｐ

型窒化物半導体層の抵抗値を極めて低くできるので、窒化物半導体素子の電力効率を高くすることができる。また、本発明に係る第１の窒化物半導体素子において、前記超格子層は、１００Å以下の膜厚を有する窒化物半導体からなる第１の層と該第１の層と組成が異なりかつ１００Å以下の膜厚を有する窒化物半導体からなる第２の層とが積層されているので、前記超格子層の結晶性を良くできる。ｐ型のクラッド層に超格子構造を適用することによる閾値電流、電圧を低げる効果は大きく、本発明では、閾値電流、電圧を顕著に低下させることができる。

【０００８】本発明に係る第１の窒化物半導体素子では、前記第１の層及び前記第２の層の内の少なくとも一方に、ｐ型不純物をドープすることが好ましく、前記第１の層及び前記第２の層にドープされたｐ型不純物の濃度は互いに異なっていることが好ましい。また、上記第１の窒化物半導体素子では、前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なる場合、バンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【０００９】また、本発明に係る第２の窒化物半導体素子は、基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、前記ｐ側クラッド層及び前記ｎ側クラッド層のうち少なくとも一つは、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であることを特徴とする。

【００１０】本発明に係る第２の窒化物半導体素子において、前記ｐ側クラッド層が前記超格子層である場合には、前記第１の層及び前記第２の層の内の少なくとも一方に、ｐ型不純物をドープすることが好ましく、また、前記第１の層及び前記第２の層にドープされたｐ型不純物の濃度は互いに異なっていることが好ましい。本発明に係る第２の窒化物半導体素子では、前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なる場合、バンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【００１１】本発明に係る第２の窒化物半導体素子において、前記ｎ側クラッド層が前記超格子層である場合には、前記第１の層及び前記第２の層の内の少なくとも一方にｎ型不純物をドープすることが好ましく、また、記第１の層及び前記第２の層、にドープされたｎ型不純物の濃度が互いに異なっていることが好ましい。この際、前記第１の層と前記第２の層とのバンドギャップエネルギーが互いに異なる場合、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【００１２】また、本発明に係る第３の窒化物半導体素子は、基板上に、ｎ側コンタクト層、ｎ側クラッド層及びｎ側光ガイド層が積層されたｎ型窒化物半導体層領域と、窒化物半導体からなる活性層と、ｐ側光ガイド層、ｐ側クラッド層及びｐ側コンタクト層が積層されたｐ型窒化物半導体層領域とを有する窒化物半導体素子であって、前記ｎ側クラッド層が、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第１の層と、該第１の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第２の層とが積層された超格子層であり、かつ前記ｐ側クラッド層が、１０Å以上で１００Å以下の膜厚を有し、Ａｌを含まない窒化物半導体からなる第３の層と、該第３の層と組成が異なりかつ１０Å以上で１００Å以下の膜厚を有し、Ａｌを含む窒化物半導体からなる第４の層とが積層された超格子層であることを特徴とする。

【００１３】上記第３の窒化物半導体素子では、前記ｐ側クラッド層及び該ｐ側クラッド層より上に形成されている層において、共振方向に峰状のリッジ部を形成するようにしてもよい。

【００１４】本発明に係る第１～第３の窒化物半導体素子では、前記活性層は、インジウムを含む窒化物半導体を有していてもよい。また、前記第１～第３の窒化物半導体素子は、サファイア基板のＣ面上に形成するようにしてもよいし、前記第１～第３の窒化物半導体素子は、サファイア基板のＣ面上にＳｉをドープしたＧａＮ層を成長させた後、サファイア基板を除去したＧａＮ基板上に形成するようにしてもよい。前記第１～第３の窒化物半導体素子において、前記ｎ側光ガイド層はＧａＮであってもよいし、ＩｎＧａＮであってもよい。前記第１～第３の窒化物半導体素子において、前記ｐ側光ガイド層はＧａＮであってもよいし、ＩｎＧａＮであってもよい。前記第１～第３の窒化物半導体素子において、前記活性層に接して、Ａｌを含む窒化物半導体よりなるｐ側キャップ層を有し、そのｐ側キャップ層よりも活性層から離れた位置に、前記ｐ側キャップ層よりもバンドギャップエネルギーが小さいｐ側光ガイド層を設けるようにすることが好ましい。

【００１５】また、本発明の第１～第３の窒化物半導体素子において、超格子層を$In_{X}Ga_{1-X}N$（$0 \leqq X \leqq 1$）からなる第１の層と、$Al_{Y}Ga_{1-Y}N$（$0 \leqq Y \leqq 1$、$X = Y \neq 0$）からなる第２の層とを積層することにより構成すると、一般式$Al_{Y}Ga_{1-Y}N$、及び$In_{X}Ga_{1-X}N$で表される窒化物半導体は結晶性の良い半導体層が得られることから、結晶欠陥の少ない層を形成できる。これにより、窒化物半導体全体の結晶性

が良くなり、該素子の出力を向上（電力効率の向上）、該素子がＬＥＤ素子又はＬＤ素子である場合には、Ｖｆ、閾値電流、電圧等を低くすることができる。尚、本発明の第１～第３の窒化物半導体素子では、さらに結晶欠陥の少ない層を形成するために、前記超格子層において、前記第１の層が式$In_X Ga_{1-X} N$（０≦Ｘ＜１）で表される窒化物半導体からなり、かつ前記第２の層が式$Al_Y Ga_{1-Y} N$（０＜Ｙ＜１）で表される窒化物半導体からなることがさらに好ましい。

【００１６】また、本発明の第１～第３の窒化物半導体素子において、前記第１の層、及び第２の層の膜厚は、上述のように、７０Å以下であることが好ましいが、さらに好ましくは４０Å以下に設定する。また、本発明では、前記第１の層、及び第２の層の膜厚は１０Å以上に設定する。この範囲内に設定することにより、従来では成長させにくかった$Al_Y Ga_{1-Y} N$（０＜Ｙ≦１）等の窒化物半導体層が結晶性良く形成することができる。特に、ｐ電極と活性層との間にあるｐ型窒化物半導体層の内の少なくとも一層、及び／又はｎ電極が形成される電流注入層としてのｎ側コンタクト層と活性層との間にあるｎ型窒化物半導体層の内の少なくとも一層を超格子層とする場合に、その超格子層を構成する第１の層、及び第２の層を前記膜厚に設定することによる効果が大きい。

【００１７】また、本発明の第１～第３の窒化物半導体素子においては、ｐ電極を形成するためのｐ側コンタクト層を備え、該ｐ側コンタクト層の膜厚を５００Å以下に設定することが好ましい。このように、ｐ側コンタクト層を薄く形成することにより、該ｐ側コンタクト層の厚さ方向の抵抗値を下げることができる。本発明では、３００Å以下に設定することがさらに好ましい。また、該ｐ側コンタクト層の膜厚の下限は、該ｐ型コンタクト層の下の半導体層を露出させないように、１０Å以上に設定することが好ましい。

【００１８】また、本発明では、基板上に第１のバッファ層を形成し、その上に膜厚０．１μｍ以上の窒化物半導体からなる第２のバッファ層を形成して、該第２のバッファ層上に、ｎ型不純物がドープされた窒化物半導体からなるｎ側コンタクト層を形成することが好ましい。これによって、キャリア濃度が大きく結晶性のよいｎ側コンタクト層を形成することができる。さらに結晶性のよい、前記第２バッファ層を形成するために、前記第２のバッファ層の不純物濃度が、前記ｎ側コンタクト層に比較して低濃度であることが好ましい。

【００１９】なお、本発明において、導電型を決定する不純物としては、窒化物半導体にドープされる周期律表第４Ａ族、４Ｂ族、第６Ａ族、第６Ｂ族に属するｎ型不純物と、１Ａ、１Ｂ族、２Ａ族、２Ｂ族に属するｐ型不純物とがある（以下、本明細書において、適宜ｎ型不純物、ｐ型不純物と記する。）。さらに、上述したように、第１の層と第２の層とでバンドギャップエネルギーが異なる場合には、バンドギャップエネルギーの大きい方の層の不純物濃度を大きくすることが望ましい。これによって、ｐ型窒化物半導体層側に超格子層を形成した場合の変調ドープによる高出力化が期待できる。本発明では、ｎ側コンタクト層が超格子層であってもよい。ｎ側コンタクト層である超格子層を構成する２つの層でバンドギャップエネルギーが互いに異なり、バンドギャップエネルギーの大きい方の層の不純物濃度を大きくすることにより、後述するＨＥＭＴに類似したような効果により電力効率を向上させることができる。例えば、レーザ素子では、さらに閾値電圧、閾値電流が低下する傾向にある。

【００２０】

【発明の実施の形態】以下、図面を参照して本発明に係る実施の形態の窒化物半導体素子について説明する。

実施形態１．図１は、本発明に係る実施形態１の窒化物半導体素子の構造を示す模式的な断面図であり、該窒化物半導体素子は、基本的な構造として、サファイアよりなる基板１の上に、ＧａＮよりなるバッファ層２、Ｓｉドープｎ型ＧａＮよりなるｎ側コンタクト層３、単一量子井戸構造のＩｎＧａＮよりなる活性層４、互いに組成の異なる第１の層と第２の層とが積層された超格子層よりなるｐ側クラッド層５、ＭｇドープＧａＮよりなるｐ側コンタクト層６とが順に積層されているＬＥＤ素子である。なお、実施形態１の窒化物半導体素子において、ｐ側コンタクト層６表面のほぼ全面には、透光性の全面電極７が形成され、全面電極７の表面にはボンディング用のｐ電極８が設けられており、さらにｐ側コンタクト層６より窒化物半導体層の一部をエッチング除去して露出されたｎ側コンタクト層２の表面にはｎ電極９が設けられている。

【００２１】ここで、実施形態１の窒化物半導体素子は、例えばｐ型不純物としてＭｇをドープした$In_X Ga_{1-X} N$（０≦Ｘ≦１）よりなる膜厚３０オングストローム（Å）の第１の層と、同じくｐ型不純物としてＭｇを第１の層と同量でドープしたｐ型$Al_Y Ga_{1-Y} N$（０≦Ｙ≦１）よりなる膜厚３０オングストロームの第２の層とが積層された超格子層で構成された低い抵抗値を有するｐ側クラッド層５を備えているので、Ｖｆを低くできる。このように超格子層をｐ層側に形成する場合は、Ｍｇ、Ｚｎ、Ｃｄ、Ｂｅ等のｐ型不純物を第１の層、及び／又は第２の層にドープしてｐ型の導電型を有する超格子層とする。積層順としては、第１＋第２＋第１・・・、若しくは第２＋第１＋第２・・・の順でも良く、少なくとも合計２層以上積層する。

【００２２】尚、超格子層を構成する窒化物半導体よりなる第１の層及び第２の層は、$In_X Ga_{1-X} N$（０≦Ｘ≦１）よりなる層及び$Al_Y Ga_{1-Y} N$（０≦Ｙ≦１）よりなる層に限定されるわけではなく、互いに組

成が異なる窒化物半導体で構成されていれば良い。また、第１の層と第２の層とのバンドギャップエネルギーが異なっていても、同一でもかまわない。例えば、第１の層を$In_X Ga_{1-X}$ N（０≦Ｘ≦１）で構成し、第２の層を$Al_Y Ga_{1-Y}$ N（０＜Ｙ≦１）で構成すると、第２の層のバンドギャップエネルギーが必ず第１の層よりも大きくなるが、第１の層を$In_X Ga_{1-X}$ N（０≦Ｘ≦１）で構成し、第２の層を$In_Z Al_{1-Z}$ N（０＜Ｚ≦１）で構成すれば、第１の層と第２の層とは組成が異なるがバンドギャップエネルギーが同一の場合もあり得る。また第１の層を$Al_Y Ga_{1-Y}$ N（０≦Ｙ≦１）で構成し、第２の層を$In_Z Al_{1-Z}$ N（０＜Ｚ≦１）で構成すれば、同様に第１の層と第２の層とは組成が異なるがバンドギャップエネルギーが同一の場合もあり得る。すなわち、本発明は、後述する作用を有する超格子層であれば、第１の層と第２の層のバンドギャップエネルギーが同じであっても、異なっていても良い。以上のように、ここで言う超格子層とは、組成の異なる極めて薄い層が積層されたものであって、各層の厚さが十分薄いために、格子不整に伴う欠陥が発生することなく積層された層のことをいい、量子井戸構造を含む広い概念である。また、この超格子層は、内部に欠陥は有しないが、通常、格子不整に伴う歪みを有するので歪み超格子とも呼ばれる。本発明において、第１の層、第２の層のＮ（窒素）を一部Ａｓ、Ｐ等のV族元素で置換してもＮが存在している限り窒化物半導体に含まれる。

【００２３】本発明において、超格子層を構成する第１の層、第２の層の膜厚は、１００オングストロームよりも厚いと、第１の層及び第２の層が弾性歪み限界以上の膜厚となり、該膜中に微少なクラック、あるいは結晶欠陥が入りやすくなるので、１００オングストローム以下の膜厚に設定することが好ましい。また、第１の層、第２の層の膜厚の下限は特に限定されず１原子層以上であればよい。しかしながら、本発明では、第１の層、第２の層の膜厚は、１００オングストロームであると窒化物半導体の臨界（弾性歪み）限界膜厚に十分に達しておらず、弾性歪み限界膜厚以下にして窒化物半導体の結晶欠陥をより少なくするため７０オングストローム以下に設定することが好ましく、さらに好ましくはより薄く設定し、４０オングストローム～１０オングストロームに設定することが最も好ましい。また、本発明では、１０オングストローム以下（１原子層又は２原子層）に設定してもよいが、１０オングストローム以下に設定すると、例えば、５００オングストローム以上の膜厚のクラッド層を超格子層で形成する場合、積層数が多くなるり、製造工程上、形成時間及び手間がかかるので、第１の層、第２の層の膜厚は、１０オングストロームより厚く設定することが好ましい。

【００２４】図１に示す本実施形態１の窒化物半導体素子の場合、超格子層よりなるｐ型クラッド層５は、活性層４と電流注入層であるｐ側コンタクト層６との間に形成されて、キャリア閉じ込め層として作用している。このように、特に超格子層をキャリア閉じ込め層とする場合には、超格子層の平均バンドギャップエネルギーを活性層よりも大きくする必要がある。窒化物半導体では、ＡｌＮ、ＡｌＧａＮ、ＩｎＡｌＮ等のＡｌを含む窒化物半導体が、比較的大きなバンドギャップエネルギーを有するので、キャリア閉じ込め層としてこれらの層が用いられる。しかし、従来のようにＡｌＧａＮ単一で厚膜を成長させると結晶成長中にクラックが入りやすい性質を有している。

【００２５】そこで、本発明では、超格子層の第１の層、及び第２の層の内の少なくとも一方を少なくともＡｌを含む窒化物半導体、好ましくは$Al_Y Ga_{1-Y}$ N（０＜Ｙ≦１）を弾性歪み限界以下の膜厚で形成して超格子層を構成することにより、クラックの少ない非常に結晶性の良い超格子層を成長形成させ、しかもバンドギャップエネルギーが大きな層を形成している。この場合さらに好ましくは、第１の層にＡｌを含まない窒化物半導体層を１００オングストローム以下の膜厚で成長させると、Ａｌを含む窒化物半導体よりなる第２の層を成長させる際のバッファ層としても作用し、第２の層にクラックを入りにくくする。そのため第１の層と第２の層とを積層してもクラックのない結晶性のよい超格子層を形成できる。従って、本実施形態１では、超格子層を$In_X Ga_{1-X}$ N（０≦Ｘ≦１）からなる第１の層（第２の層）と$Al_Y Ga_{1-Y}$ N（０≦Ｙ≦１、Ｘ≠Ｙ＝０）からなる第２の層（第１の層）とすることが好ましい。

【００２６】また、本実施形態１の窒化物半導体素子において、超格子層であるｐ側クラッド層５を構成する第１の層及び第２の層の内の少なくとも一方の層には、キャリア濃度を調整するために、該層の導電型をｐ型に設定するｐ型の不純物がドープされることが好ましい。また、第１の層と第２の層とにｐ型の不純物をドープする場合、第１の層と第２の層とで異なる濃度でドープてもよく、さらに、第１の層と第２の層とのバンドギャップエネルギーが異なる場合には、バンドギャップエネルギーが大きな層の方を高濃度とすることが望ましい。なぜなら、第１の層、第２の層にそれぞれ異なる濃度で不純物をドープすると、変調ドーピングによる量子効果によって、一方の層のキャリア濃度が実質的に高くなり超格子層全体の抵抗値を低下させることができるからである。このように、本発明では、第１の層と、第２の層の両方に不純物を異なる濃度でそれぞれドープしても良いし、第１の層、第２の層のいずれか一方に不純物をドープしても良い。

【００２７】なお、第１の層及び第２の層にドープされる不純物濃度は、特に本発明はこれに限定されないが、

ｐ型不純物で通常、$1\times10^{16}/cm^{3}\sim1\times10^{22}/cm^{3}$、さらに好ましくは$1\times10^{17}/cm^{3}\sim1\times10^{21}/cm^{3}$、最も好ましくは$1\times10^{18}/cm^{3}\sim2\times10^{20}/cm^{3}$の範囲に調整することが望ましい。$1\times10^{16}/cm^{3}$よりも少ないとＶｆ、閾値電圧を低下させる効果が得られにくく、$1\times10^{22}/cm^{3}$よりも多いと超格子層の結晶性が悪くなる傾向にあるからである。またｎ型不純物も同様の範囲に調整することが望ましい。理由は同じである。

【００２８】しかしながら、本発明では、超格子層には、第１の層及び第２の層に導電型を決定する不純物がドープされていなくてもよい。この不純物がドープされない超格子層は、ｎ型窒化物半導体層領域であれば活性層と基板との間におけるいずれの層であってもよく、一方、ｐ型窒化物半導体層領域であれば、キャリア閉じ込め層（光閉じ込め層）と、活性層との間におけるいずれの層であってもよい。

【００２９】以上のように構成された超格子層は、第１の層、及び第２の層を弾性歪み限界以下の膜厚にして積層して形成しているので、結晶の格子欠陥を低下させることができ、かつ微少なクラックを減少させることができ、結晶性を飛躍的に良くすることができる。この結果、結晶性をあまり損なうことなく、不純物のドープ量を多くでき、これによって、ｎ型窒化物半導体層、ｐ型窒化物半導体層のキャリア濃度を増加させることができ、かつ該キャリアが結晶欠陥によって散乱されることなく移動できるので、超格子構造を有しないｐ型又はｎ型の窒化物半導体に比較して抵抗率を１桁以上低くすることができる。

【００３０】従って、本実施形態１の窒化物半導体素子（ＬＥＤ素子）では、従来、低抵抗な窒化物半導体層を得ることが困難であったｐ層側（ｐ型半導体層領域（ｐ型クラッド層５とｐ型コンタクト層６とからなる領域））のｐ型クラッド層５を超格子層を用いて形成して、該ｐ型クラッド層５の抵抗値を低くすることにより、Ｖｆを低くすることができる。つまり、ｐ型窒化物半導体は、ｐ型結晶が非常に得られにくい半導体であり、得られたとしても、ｎ型窒化物半導体に比べて、通常抵抗率が２桁以上高い。そのためｐ型の超格子層をｐ層側に形成することにより、超格子層で構成されたｐ型層を極めて低抵抗にすることができ、Ｖｆの低下が顕著に現れる。従来、ｐ型結晶を得るため技術として、ｐ型不純物をドープした窒化物半導体層をアニーリングして、水素を除去することによりｐ型の窒化物半導体を作製する技術が知られている（特許第２５４０７９１号）。しかし、ｐ型の窒化物半導体が得られたといってもその抵抗率は、数Ω・ｃｍ以上もある。そこで、このｐ型層をｐ型の超格子層とすることにより結晶性が良くなり、我々の検討によると、該ｐ層の抵抗率を従来に比較して、１桁以上低くすることができ、Ｖｆの低下させる効果が顕著に現れる。

【００３１】また、本実施形態１では、前記のように好ましくは第１の層（第２の層）を$In_{X}Ga_{1-X}N$（$0\leqq X\leqq1$）とし、第２の層（第１の層）を$Al_{Y}Ga_{1-Y}N$（$0\leqq Y\leqq1$、$X\neq Y=0$）で構成することにより、結晶性のよいクラックのない超格子層を形成することができるので、素子寿命を向上させることができる。

【００３２】次に、我々が以前に出願した特許公報を含む公知文献に開示された従来例と本発明とを比較して説明する。まず、本発明に類似した技術として、我々は先に特開平８－２２８０４８号を提案した。この技術は活性層を挟むｎ型クラッド層の外側、及び／又はｐ型クラッド層の外側（つまり活性層からより離れた側）にレーザ光の光反射膜としてＡｌＧａＮ、ＧａＮ、ＩｎＧａＮ等よりなる多層膜を形成する技術である。この技術は光反射膜として多層膜を形成するので、その各層の膜厚がλ／４ｎ（ｎ:窒化物半導体の屈折率、λ：波長）で設計されるため非常に厚い。従って多層膜の各膜厚が弾性歪み限界以下の膜厚ではない。また、ＵＳＰ　５，１４６，４６５号には活性層を$Al_{X}Ga_{1-X}N/Al_{Y}Ga_{1-Y}N$よりなるミラーで挟んだ構造のレーザ素子が記載されている。この技術も前技術と同様にＡｌＧａＮ／ＡｌＧａＮをミラーとして作用させるために、各層の膜厚を厚くしなければならない。さらにＡｌＧａＮのような硬い半導体をクラックなしに何層も積層することは非常に難しい。

【００３３】一方、本実施形態では超格子層を構成するように第１と第２の層の各膜厚を、設定（好ましくは、両方とも１００オングストローム以下と臨界膜厚以下に設定する。）しており、前記技術とは異なる。本発明では超格子層を構成する窒化物半導体の歪み超格子による効果を利用し、結晶性を向上させて、Ｖｆを低下させている。

【００３４】さらに、特開平５－１１０１３８、特開平５－１１０１３９号公報には薄膜のＡｌＮとＧａＮとを積層して$Al_{Y}Ga_{1-Y}N$の結晶を得る方法が記載されている。この技術は、所定の混晶比の$Al_{Y}Ga_{1-Y}N$の混晶を得るために、数十オングストロームの膜厚のＡｌＮ、ＧａＮを積層する技術であって本発明の技術とは異なる。しかもＩｎＧａＮよりなる活性層を有していないので、超格子層にクラックが入りやすい。また、特開平６－２１５１１号、６－２６８２５７号公報ではＧａＮとＩｎＧａＮ、若しくはＩｎＧａＮとＩｎＧａＮとを積層した多重量子井戸構造の活性層を有するダブルヘテロ構造の発光素子が記載されている。本発明では活性層以外の層を多重量子井戸構造とする技術であり、この技術とも異なる。

【００３５】さらに本発明の素子ではＩｎＧａＮのような、少なくともインジウムを含む窒化物半導体を活性層

に備える場合に、超格子の効果が顕著に現れる。ＩｎＧａＮ活性層はバンドギャップエネルギーが小さく窒化物半導体素子の活性層としては最も適している。そのため$In_XGa_{1-X}N$と、$Al_YGa_{1-Y}N$よりなる超格子層を、活性層を挟設する層として形成すると、活性層とバンドギャップエネルギー差、屈折率差を大きくできるため、該超格子層がレーザ素子を実現する際に非常に優れた光閉じ込め層として動作する（実施形態２の窒化物半導体素子に適用）。さらにＩｎＧａＮは結晶の性質が他のＡｌＧａＮのようなＡｌを含む窒化物半導体に比べて柔らかいので、ＩｎＧａＮを活性層とすると、積層した各窒化物半導体層全体にクラックが入りにくくなる。逆にＡｌＧａＮのような窒化物半導体を活性層とすると、その結晶の性質が硬いために結晶全体にクラックが入りやすくなる傾向にある。

【００３６】さらにｐ側コンタクト層の膜厚を５００オングストローム以下、さらに好ましくは３００オングストローム以下、最も好ましくは２００オングストローム以下に調整することが望ましい。なぜなら、上述したように抵抗率が数Ω・cm以上もあるｐ型窒化物半導体層の膜厚を５００オングストローム以下に調整することにより、さらに抵抗率を低げることができるため、閾値での電流、電圧が低下する。またｐ型層から除去される水素の量を多くすることができ、さらに抵抗率を低下させることができる。

【００３７】以上、詳述したように、本実施の形態１の窒化物半導体素子では、ｐ型クラッド層５を第１の層と第２の層とが積層された超格子層で構成しているので、該ｐ型クラッド層５を極めて低抵抗にでき、該素子のＶｆを低くできる。

【００３８】以上の実施形態１では、ｐ側クラッド層５に超格子層を用いたが、本発明はこれに限らず、ｐ側コンタクト層６にｐ型の超格子層を用いてもよい。すなわち、電流（正孔）が注入されるｐ側コンタクト層６も例えば$In_XGa_{1-X}N$よりなる第１の層と、$Al_YGa_{1-Y}N$よりなる第２の層とが積層されたｐ型の超格子層とすることもできる。ｐ型コンタクト層６を超格子層として、第１の層のバンドギャップエネルギーが第２の層よりも小さい場合、バンドギャップエネルギーが小さい$In_XGa_{1-X}N$よりなる第１の層を最表面にしてｐ電極と接触する層とすることが好ましく、これによって、ｐ電極との接触抵抗が小さくなり好ましいオーミックが得られる。これはバンドギャップエネルギーが小さい第１の層の方が、第２の層よりもキャリア濃度の高い窒化物半導体層が得られやすい傾向にあるからである。また、本発明では、ｐ型窒化物半導体層領域に、上述のｐ側クラッド層及びｐ側コンタクト層以外のｐ型窒化物半導体層をさらに形成する場合は、該ｐ型窒化物半導体層を超格子層で構成してもよい。

【００３９】以上の実施形態１では、ｐ側クラッド層５に超格子層を用いたが、本発明はｐ型窒化物半導体層領域に限らず、ｎ型窒化物半導体領域のｎ側コンタクト層３にｎ型の超格子層を用いてもよい。このように、ｎ側コンタクト層３を超格子層とする場合は、例えば、Ｓｉ、Ｇｅ等のｎ型不純物を第１の層及び／又は第２の層にドープして、ｎ型の導電型を有する超格子層を基板１と活性層４との間にｎ型コンタクト層３として形成することができる。この場合、特にｎ型コンタクト層３を不純物濃度が異なる超格子層とすると横方向の抵抗値が低下して、ＬＤでは閾値電圧、電流が低下する傾向にあることが確認された。

【００４０】これは、バンドギャップエネルギーの大きな層の方に、多くｎ型不純物をドープした超格子層をｎ層側のコンタクト層として形成した場合について、以下のようなＨＥＭＴ（High-Electron-Mobility-Transistor）に類似した作用が出現した効果が推察される。ｎ型不純物がドープされたバンドギャップの大きい第１の層（第２の層）と、バンドギャップが小さいアンドープ｛（ｕｎｄｏｐｅ）；以下、不純物がドープされていない状態をアンドープという｝の第２の層（第１の層）とを積層した超格子層では、ｎ型不純物を添加した層と、アンドープの層とのヘテロ接合界面で、バンドギャップエネルギーの大きな層側が空乏化し、バンドギャップエネルギーの小さな層側の厚さ（１００オングストローム）前後の界面に電子（二次元電子ガス）が蓄積する。この二次元電子ガスがバンドギャップエネルギーの小さな層側にできるので、電子が走行するときに不純物による散乱を受けないため、超格子層の電子の移動度が高くなり、抵抗率が低下すると推察される。

【００４１】また、本発明において、ｎ型窒化物半導体層領域にｎ側のクラッド層を設ける場合は、該ｎ側のクラッド層を超格子層としてもよい。ｎ型窒化物半導体層領域にｎ側コンタクト層及びｎ側クラッド層以外のｎ型窒化物半導体層を形成する場合は、該ｎ型窒化物半導体層を超格子層としてもよい。しかし、ｎ型窒化物半導体層領域に超格子層からなる窒化物半導体層を設ける場合、キャリア閉じ込め層としてのｎ側クラッド層、若しくは電流（電子）が注入されるｎ側コンタクト層３を超格子構造とすることが望ましいことはいうまでもない。

【００４２】このように、超格子層を活性層４と基板１との間のｎ型窒化物半導体層領域にに設ける場合、超格子層を構成する第１の層、第２の層には不純物をドープしなくても良い。なぜなら窒化物半導体はアンドープでもｎ型になる性質があるからである。但し、ｎ層側に形成する場合においても上述のように、第１の層、第２の層にＳｉ、Ｇｅ等のｎ型不純物をドープして、不純物濃度の差を設ける方が望ましい。

【００４３】以上のように、超格子層をｎ型窒化物半導体層領域に形成した場合の効果は、超格子層をｐ型窒化物半導体層領域に設けた場合と同様に、結晶性の向上が

挙げられる。詳細に説明すると、ヘテロ接合を有する窒化物半導体素子の場合、通常ｎ型、ｐ型のキャリア閉じ込め層は、活性層よりもバンドギャップエネルギーが大きいＡｌＧａＮで構成される。ＡｌＧａＮは結晶成長が非常に難しく、例えば単一組成で０．５μm以上の膜厚で成長させようとすると、結晶中にクラックが入りやすくなる性質がある。しかしながら、本発明のように第１の層と、第２の層とを弾性歪み限界以下の膜厚で積層して超格子層とすると、単一の第１の層、第２の層のみで結晶性の良いものが得られるため、全体を膜厚の厚い超格子層としても結晶性が良いままでクラッド層が成長できる。そのため全体の窒化物半導体の結晶性が良くなってｎ型領域の移動度が大きくなるので、その超格子層をクラッド層とした素子でＶｆが低下する。さらに、超格子層にＳｉ、Ｇｅの不純物をドープして、超格子層をコンタクト層とした場合には前記したＨＥＭＴに類似した効果が顕著に現れてくるようになると思われ、閾値電圧、Ｖｆをさらに低下させることができる。

【００４４】このように、本発明において、超格子層は、活性層を挟設するｎ型領域又はｐ型領域に形成されるキャリア閉じ込め層としてのクラッド層、活性層の光ガイド層、若しくは電極が接して形成される電流注入層として用いられるため、超格子層を構成する窒化物半導体の平均バンドギャップエネルギーが活性層よりも大きくなるように調整することが望ましい。

【００４５】実施形態２．次に、本発明に係る実施形態２について説明する。図２は、本発明に係る実施形態２の窒化物半導体素子の構造を示す模式的な断面図（レーザ光の共振方向に垂直な断面）であり、該窒化物半導体素子は、例えば、Ｃ面を主面とするサファイヤ等の基板１０上に、ｎ型窒化物半導体層領域（ｎ側コンタクト層１２、クラック防止層１３、ｎ側クラッド層１４及びｎ側光ガイド層１５からなる。）とｐ型窒化物半導体領域（キャップ層１７、ｐ側光ガイド層１８、ｐ側クラッド層１９及びｐ側コンタクト層２０からなる。）とによって挟設された窒化物半導体からなる活性層１６を備えた窒化物半導体レーザダイオード素子である。

【００４６】ここで、本実施形態２の窒化物半導体素子は、ｎ型窒化物半導体層領域におけるｎ側クラッド層１４を超格子層で形成し、かつｐ型窒化物半導体領域におけるｐ側クラッド層１９を超格子層で形成することにより、ＬＤ素子である窒化物半導体素子の閾値電圧を低く設定している。以下この図２を参照して本発明に係る実施形態２の窒化物半導体素子について詳細に説明する。

【００４７】この実施形態２の窒化物半導体素子においては、まず、基板１０上にバッファ層１１と第２のバッファ層１１２を介してｎ側コンタクト層１２が形成され、さらにｎ側コンタクト層１２上に、クラック防止層１３、ｎ側クラッド層１４及びｎ側光ガイド層１５が積層されて、ｎ型窒化物半導体層領域が形成される。尚、クラック防止層１３の両側に露出されたｎ側コンタクト層１２の表面にはそれぞれ、ｎ側コンタクト層１２とオーミック接触するｎ側電極２３が形成され、該ｎ側電極２３上には、例えば、ワイヤーボンディング用のｎ側パッド電極が形成される。そして、ｎ側光ガイド層１５上に窒化物半導体からなる活性層１６が形成され、さらに該活性層１６上に、キャップ層１７、ｐ側光ガイド層１８、ｐ側クラッド層１９及びｐ側コンタクト層２０が積層されてｐ型窒化物半導体層領域が形成される。さらに、ｐ側コンタクト層２０上に該ｐ側コンタクト層２０とオーミック接触するｐ側電極２１が形成され、該ｐ側電極２１上には、例えば、ワイヤーボンディング用のｐ側パッド電極が形成される。なお、ｐ側コンタクト層２０とｐ側クラッド層１９の上部とによって、共振方向に長く伸びた峰状のリッジ部が構成され、該リッジ部を形成することによって、活性層１６において、光りを幅方向（共振方向に直交する方向）に閉じ込め、リッジ部（ストライプ状の電極）に垂直な方向で劈開された劈開面を用いて、リッジ部の長手方向に共振する共振器を作製してレーザ発振させる。

【００４８】次に、実施形態２の窒化物半導体素子の各構成要素について説明する。

（基板１０）基板１０にはＣ面を主面とするサファイアの他、Ｒ面、Ａ面を主面とするサファイア、その他、スピネル（$MgAl_2O_4$）のような絶縁性の基板の他、ＳｉＣ（６Ｈ、４Ｈ、３Ｃを含む）、ＺｎＳ、ＺｎＯ、ＧａＡｓ、ＧａＮ等の半導体基板を用いることができる。

【００４９】（バッファ層１１）バッファ層１１は、例えばＡｌＮ、ＧａＮ、ＡｌＧａＮ、ＩｎＧａＮ等を９００℃以下の温度で成長させて、膜厚数十オングストローム～数百オングストロームに形成する。このバッファ層１１は、基板と窒化物半導体との格子定数不正を緩和するために形成するが、窒化物半導体の成長方法、基板の種類等によっては省略することも可能である。

【００５０】（第２のバッファ層１１２）第２のバッファ層１１２は、前記バッファ層１１の上に、前記バッファ層よりも高温で成長させた単結晶の窒化物半導体よりなる層であり、バッファ層１１よりも厚膜を有する。この第２のバッファ層１１２は次に成長させるｎ側コンタクト層１２よりもｎ型不純物濃度が少ない層とするか、若しくはｎ型不純物をドープしない窒化物半導体層、好ましくはＧａＮ層とすると、第２のバッファ層１１２の結晶性が良くなる。最も好ましくはｎ型不純物をアンドープのＧａＮとすると最も結晶性が良い窒化物半導体が得られる。従来のように負電極を形成するｎ側コンタクト層を数μm以上の膜厚で、高キャリア濃度の単一の窒化物半導体層で構成しようとすると、ｎ型不純物濃度の大きい層を成長させる必要がある。不純物濃度の大きい厚膜の層は結晶性が悪くなる傾向にある。このため結晶

性の悪い層の上に、活性層等の他の窒化物半導体を成長させても、結晶欠陥を他の層が引き継ぐことになって結晶性の向上が望めない。そこで、ｎ側コンタクト層１２層を成長させる前に、不純物濃度が小さい、結晶性の良い第２のバッファ層１１２を成長させることにより、キャリア濃度が大きく結晶性の良いｎ側コンタクト層１２を成長させることができる。この第２のバッファ層１１２の膜厚は、０．１μm以上、さらに好ましくは０．５μm以上、最も好ましくは１μm以上、２０μm以下に調整することが望ましい。第２のバッファ層１１２が０．１μmよりも薄いと、不純物濃度の大きいｎ型コンタクト層１２を厚く成長させなければならず、ｎ側コンタクト層１２の結晶性の向上があまり望めない傾向にある。また２０μmよりも厚いと、第２のバッファ層１１２自体に結晶欠陥が多くなりやすい傾向にある。また第２のバッファ層１１２を厚く成長させる利点として、放熱性の向上が挙げられる。つまりレーザ素子を作製した場合に、第２のバッファ層１１２で熱が広がりやすくレーザ素子の寿命が向上する。さらにレーザ光の漏れ光が第２のバッファ層１１２内で広がって、楕円形に近いレーザ光が得やすくなる。なお、第２のバッファ層１１２は、基板にＧａＮ、ＳｉＣ、ＺｎＯ等の導電性基板を使用した場合には省略してもよい。

【００５１】（ｎ側コンタクト層１２）ｎ側コンタクト層１２は負電極を形成するコンタクト層として作用する層であり、０．２μm以上、４μm以下に調整することが望ましい。０．２よりも薄いと、後で負電極を形成する際に、この層を露出させるようにエッチングレートを制御するのが難しく、一方、４μm以上にすると不純物の影響で結晶性が悪くなる傾向にある。このｎ側コンタクト層１２の窒化物半導体にドープするｎ型不純物の範囲は$1\times10^{17}/cm^3$〜$1\times10^{21}/cm^3$の範囲、さらに好ましくは、$1\times10^{18}/cm^3$〜$1\times10^{19}/cm^3$に調整することが望ましい。$1\times10^{17}/cm^3$よりも小さいとｎ電極の材料と好ましいオーミックが得られにくくなるので、レーザ素子では閾値電流、電圧の低下が望めず、$1\times10^{21}/cm^3$よりも大きいと、素子自体のリーク電流が多くなったり、また結晶性も悪くなるため、素子の寿命が短くなる傾向にある。なおｎ側コンタクト層１２においては、ｎ電極２３とのオーミック接触抵抗を小さくするために、該ｎ側コンタクト層１２のキャリア濃度を上げる不純物の濃度を、ｎクラッド層１４よりも大きくすることが望ましい。なお、ｎ側コンタクト層１２は基板にＧａＮ、ＳｉＣ、ＺｎＯ等の導電性基板を使用し基板裏面側に負電極を設ける場合にはコンタクト層としてではなくバッファ層として作用する。

【００５２】また、第２のバッファ層１１、及びｎ側コンタクト層１２の内の少なくとも一方の層を、超格子層とすることもできる。超格子層とすると、この層の結晶性が飛躍的に良くなり、閾値電流が低下する。好ましくは第２のバッファ層１１よりも膜厚が薄いｎ側コンタクト層１２の方を超格子層とする。ｎ側コンタクト層１２を互いにバンドギャップエネルギーが異なる第１の層と第２の層とが積層されてなる超格子構造とした場合においては、好ましくはバンドギャップエネルギーの小さな層を露出させてｎ電極２３を形成することにより、ｎ電極２３との接触抵抗が低くでき閾値を低下させることができる。なおｎ型窒化物半導体と好ましいオーミックが得られるｎ電極２３の材料としてはＡｌ，Ｔｉ，Ｗ，Ｓｉ，Ｚｎ，Ｓｎ，Ｉｎ等の金属若しくは合金が挙げられる。

【００５３】また、ｎ型コンタクト層１２を不純物濃度が異なる超格子層とすることにより、実施形態１において説明したＨＥＭＴに類似した効果により横方向の抵抗値を低くでき、ＬＤ素子の閾値電圧、電流を低くすることができる。

【００５４】（クラック防止層１３）クラック防止層１３は、例えば、Ｓｉを$5\times10^{18}/cm^3$ドープした$In_{0.1}Ga_{0.9}N$からなり、例えば、５００オングストロームの膜厚を有する。このクラック防止層１３はＩｎを含むｎ型の窒化物半導体、好ましくはＩｎＧａＮを成長させて形成することにより、その上に形成されるＡｌを含む窒化物半導体層中にクラックが入るのを防止することができる。なお、このクラック防止層１３は１００オングストローム以上、０．５μm以下の膜厚で成長させることが好ましい。１００オングストロームよりも薄いと前記のようにクラック防止として作用しにくく、０．５μmよりも厚いと、結晶自体が黒変する傾向にある。なお、このクラック防止層１３は、本実施形態１のようにｎ側コンタクト層１２を超格子とする場合、または次に成長させるｎ側クラッド層１４を超格子層とする場合には省略してもよい。

【００５５】（ｎ型超格子からなるｎ側クラッド層１４）ｎ側クラッド層は、例えばＳｉを$5\times10^{18}/cm^3$ドープしたｎ型Ａｌ０．２Ｇａ０．８Ｎからなり、２０オングストロームの膜厚を有する第１の層、及びアンドープのＧａＮよりなり、２０オングストロームの膜厚を有する第２の層とが交互に積層された超格子層よりなり、全体で例えば０．５μmの膜厚を有する。このｎ型クラッド層１４はキャリア閉じ込め層、及び光閉じ込め層として作用し、超格子層とした場合にはいずれか一方の層をＡｌを含む窒化物半導体、好ましくはＡｌＧａＮを成長させることが望ましく、１００オングストローム以上、２μm以下、さらに好ましくは５００オングストローム以上、１μm以下で成長させることにより良好なキャリア閉じ込め層が成長できる。このｎ型クラッド層１４は単一の窒化物半導体で成長させることもできるが、超格子層とすることがクラックのない結晶性のよいキャリア閉じ込め層が形成できる。

【００５６】（ｎ側光ガイド層１５）ｎ側光ガイド層１５は、例えば、Ｓｉを５×１０^{18}／ｃｍ^{3}ドープしたｎ型ＧａＮからなり、０．１μｍの膜厚を有する。このｎ側光ガイド層６は、活性層の光ガイド層として作用し、ＧａＮ、ＩｎＧａＮを成長させて形成することが望ましく、通常１００オングストローム～５μｍ、さらに好ましくは２００オングストローム～１μｍの膜厚で成長させることが望ましい。なお、この光ガイド層１５も超格子層にすることができる。ｎ側光ガイド層１５、ｎ側クラッド層１４を超格子層にする場合、超格子層を構成する窒化物半導体層の平均的なバンドギャップエネルギーは活性層よりも大きくする。超格子層とする場合には、第１の層及び第２の層の少なくとも一方にｎ型不純物をドープしてもよいし、またアンドープでも良い。また、この光ガイド層１５は、アンドープの窒化物半導体単独若しくはアンドープの窒化物半導体が積層された超格子でもよい。

【００５７】（活性層１６）活性層１６は、例えば、Ｓｉを８×１０^{18}／ｃｍ^{3}でドープした$In_{0.2}Ga_{0.8}N$よりなり、２５オングストロームの膜厚を有する井戸層と、Ｓｉを８×１０^{18}／ｃｍ^{3}ドープした$In_{0.05}$１$Ga_{0.95}N$よりなり、５０オングストロームの膜厚を有する障壁層とを交互に積層することにより、所定の膜厚を有する多重量子井戸構造（ＭＱＷ）で構成する。活性層１６においては、井戸層、障壁層両方に不純物をドープしても良く、いずれか一方にドープしてもよい。なおｎ型不純物をドープすると閾値が低下する傾向にある。また、このように活性層１６を多重量子井戸構造とする場合には必ずバンドギャップエネルギーの小さい井戸層と、井戸層よりもバンドギャップエネルギーが小さい障壁層とを積層するため、超格子層とは区別される。井戸層の厚さは、１００オングストローム以下、好ましくは７０オングストローム以下、最も好ましくは、５０オングストローム以下にする。障壁層の厚さは１５０オングストローム以下、好ましくは１００オングストローム以下、最も好ましくは７０オングストローム以下にする。

【００５８】（ｐ側キャップ層１７）ｐ側キャップ層１７は、活性層１６よりもバンドギャップエネルギーが大きい、例えば、Ｍｇを１×１０^{20}／ｃｍ^{3}ドープしたｐ型$Al_{0.3}Ga_{0.7}N$よりなり、例えば、２００オングストロームの膜厚を有する。本実施形態２では、このように、キャップ層１７を用いることが好ましいが、このキャップ層は、薄い膜厚に形成されるので、本発明では、ｎ型不純物をドープしてキャリアが補償されたｉ型としても良い。ｐ側キャップ層１７の膜厚は０．１μｍ以下、さらに好ましくは５００オングストローム以下、最も好ましくは３００オングストローム以下に調整する。０．１μｍより厚い膜厚で成長させると、ｐ側キャップ層１７中にクラックが入りやすくなり、結晶性の良い窒化物半導体層が成長しにくいからである。また、ｐ側キャップ層１７の膜厚が、０．１μｍ以上であると、キャリアがこのエネルギーバリアとなるｐ型キャップ層１７をトンネル効果により通過できなくなるからであり、該トンネル効果によるキャリアの通過を考慮すると、上述したように５００オングストローム以下、さらには３００オングストローム以下に設定することが好ましい。

【００５９】また、ｐ側キャップ層１７には、ＬＤ素子を発振しやすくするために、Ａｌの組成比が大きいＡｌＧａＮを用いて形成することが好ましく、該ＡｌＧａＮを薄く形成する程、ＬＤ素子は発振しやすくなる。例えば、Ｙ値が０．２以上の$Al_{Y}Ga_{1-Y}N$であれば５００オングストローム以下に調整することが望ましい。ｐ側キャップ層１７の膜厚の下限は特に限定しないが、１０オングストローム以上の膜厚で形成することが望ましい。

【００６０】（ｐ側光ガイド層１８）ｐ側光ガイド層１８は、バンドギャップエネルギーがｐ側キャップ層１７よりも小さい、例えば、Ｍｇを１×１０^{20}／ｃｍ^{3}ドープしたｐ型ＧａＮよりなり、０．１μｍの膜厚を有する。このｐ側光ガイド層１８は、活性層１６の光ガイド層として作用し、ｎ側光ガイド層１５と同じくＧａＮ、ＩｎＧａＮで成長させて形成することが望ましい。また、この層はｐ側クラッド層１９を成長させる際のバッファ層としても作用し、１００オングストローム～５μｍ、さらに好ましくは２００オングストローム～１μｍの膜厚で成長させることにより、好ましい光ガイド層として作用する。このｐ側光ガイド層は通常はＭｇ等のｐ型不純物をドープしてｐ型の導電型とするが、特に不純物をドープしなくても良い。なお、このｐ側光ガイド層を超格子層とすることもできる。超格子層とする場合には第１の層及び第２の層の少なくとも一方にｐ型不純物をドープしてもよいし、またアンドープでも良い。

【００６１】（ｐ側クラッド層１９＝超格子層）ｐ側クラッド層１９は、例えば、Ｍｇを１×１０^{20}／ｃｍ^{3}ドープしたｐ型$Al_{0.2}Ga_{0.8}N$よりなり、例えば、２０オングストロームの膜厚を有する第１の層と、例えばＭｇを１×１０^{20}／ｃｍ^{3}ドープしたｐ型ＧａＮよりなり、２０オングストロームの膜厚を有する第２の層とが交互に積層された超格子層からなる。このｐ側クラッド層１９は、ｎ側クラッド層１４と同じくキャリア閉じ込め層として作用し、特にｐ型層の抵抗率を低下させるための層として作用する。このｐ側クラッド層１９の膜厚も特に限定しないが、１００オングストローム以上、２μｍ以下、さらに好ましくは５００オングストローム以上、１μｍ以下で形成することが望ましい。

【００６２】（ｐ側コンタクト層２０）ｐ側コンタクト層２０は、ｐ側クラッド層１９の上に、例えば、Ｍｇを２×１０^{20}／ｃｍ^{3}ドープしたｐ型ＧａＮよりなり、

例えば、１５０オングストロームの膜厚を有する。このｐ側コンタクト層２０はｐ型の$In_{X}Al_{Y}Ga_{1-X-Y}N$（０≦Ｘ、０≦Ｙ、Ｘ＋Ｙ≦１）で構成することができ、好ましくは、上述のようにＭｇをドープしたＧａＮとすれば、ｐ電極２１と最も好ましいオーミック接触が得られる。さらにｐ側コンタクト層の膜厚を５００オングストローム以下、さらに好ましくは３００オングストローム以下、最も好ましくは２００オングストローム以下に調整することが望ましい。なぜなら、上述したように抵抗率が数Ω・ｃｍ以上もあるｐ型窒化物半導体層の膜厚を５００オングストローム以下に調整することにより、さらに抵抗率を低げることができるため、閾値での電流、電圧が低下する。またｐ型層から除去される水素の量を多くすることができ、さらに抵抗率を低下させることができる。

【００６３】なお、本発明では、ｐ側コンタクト層２０も超格子層とすることもできる。超格子層とする場合には、特にバンドギャップエネルギーが異なる第１の層と第２の層とを積層し、第１＋第２＋第１＋第２＋・・・というように積層していき、最後にバンドギャップエネルギーが小さい方の層が露出するようにすると、ｐ電極２１と好ましいオーミック接触が得られる。ｐ電極２１の材料としては、例えばＮｉ、Ｐｄ、Ｎｉ／Ａｕ等を挙げることができる。

【００６４】また、本実施形態２では、図２に示すようにｐ電極２１と、ｎ電極２３との間に露出した窒化物半導体層の表面にSiO_2よりなる絶縁膜２５が形成され、この絶縁膜２５に形成された開口部を介してｐ電極２１と電気的に接続されたｐパッド電極２２、及びｎ電極２３と接続されたｎパッド電極２４が形成される。このｐパッド電極２２は実質的なｐ電極２１の表面積を広げて、ｐ電極側をワイヤーボンディング、ダイボンディングできるようにし、一方ｎパッド電極２４はｎ電極２３の剥がれを防止する。

【００６５】以上の実施形態２の窒化物半導体素子は、第１の層、及び第２の層を弾性歪み限界以下の膜厚にして積層された超格子層である、結晶性のよいｐ型クラッド層１９を備えている。これによって、本実施形態２の窒化物半導体素子は、ｐ側クラッド層１９の抵抗値を、超格子構造を有しないｐ側クラッド層に比較して１桁以上低くすることができるので、閾値電圧、電流を低くすることができる。

【００６６】また、本実施形態２の窒化物半導体素子ではｐ型$Al_{Y}Ga_{1-Y}N$を含むｐ側クラッド層１９に接して、バンドギャップエネルギーの小さい窒化物半導体をｐ側コンタクト層２０として、その膜厚を５００オングストローム以下と薄く形成することにより、実質的にｐ側コンタクト層２０のキャリア濃度が高くなりｐ電極と好ましいオーミックが得られて、素子の閾値電流、電圧を低くすることができる。さらに、ｎ側コンタクト層を成長させる前に、第２のバッファ層１１２を備えているので、第２のバッファ層１１２の上に成長させる窒化物半導体層の結晶性が良くなり、長寿命の素子を実現できる。好ましくは、第２のバッファ層１１２の上に成長させるｎ側コンタクト層を超格子とすると、横方向の抵抗値が低くなり、閾値電圧・閾値電流の低い素子が実現できる。

【００６７】なお、本実施形態２のＬＤ素子ではＩｎＧａＮのような、少なくともインジウムを含む窒化物半導体を活性層１６に備える場合には、$In_{X}Ga_{1-X}N$と、$Al_{Y}Ga_{1-Y}N$とが交互に積層された超格子層を、活性層１６を挟設する層（ｎ側クラッド層１４及びｐ側クラッド層１９）として用いることが好ましい。これによって、活性層１６と該超格子層とのバンドギャップエネルギー差、屈折率差を大きくできるため、該超格子層をレーザ素子を実現する際に非常に優れた光閉じ込め層として動作させることができる。さらにＩｎＧａＮは結晶の性質が他のＡｌＧａＮのようなＡｌを含む窒化物半導体に比べて柔らかいので、ＩｎＧａＮを活性層とすると、積層した各窒化物半導体層全体にクラックが入りにくくなる。これによって、ＬＤ素子の寿命を長くすることができる。

【００６８】本実施形態２のように量子井戸構造を有する活性層１６を有するダブルヘテロ構造の半導体素子の場合、その活性層１６に接して、活性層１６よりもバンドギャップエネルギーが大きい膜厚０．１μｍ以下の窒化物半導体よりなるｐ側キャップ層１７、好ましくはＡｌを含む窒化物半導体よりなるｐ側キャップ層１７を設け、そのｐ側キャップ層１７よりも活性層から離れた位置に、ｐ側キャップ層１７よりもバンドギャップエネルギーが小さいｐ側光ガイド層１８を設け、そのｐ側光ガイド層１８よりも活性層から離れた位置に、ｐ側光ガイド層１８よりもバンドギャップが大きい窒化物半導体、好ましくはＡｌを含む窒化物半導体を含む超格子構造を有するｐ側クラッド層１９を設けることは非常に好ましい。しかもｐ側キャップ層１７のバンドギャップエネルギーを大きくしてあるため、ｎ層から注入された電子が、このｐ側キャップ層１７で阻止されて閉じ込められ、電子が活性層をオーバーフローしないために、素子のリーク電流が少なくなる。

【００６９】以上の実施形態２の窒化物半導体素子では、レーザ素子の構造として好ましい構造を示したが、本発明ではｎ型の超格子層は活性層１６から下のｎ型窒化物半導体層領域（ｎ型層側）に少なくとも１層有していれば良く、またｐ型の超格子層も活性層１６から上のｐ型窒化物半導体層領域（ｐ型層側）に少なくとも１層有していれば良く、素子構成は特に規定するものではない。但し、前記超格子層はｐ層側に形成する場合はキャリア閉じ込め層としてのｐ側クラッド層１９に形成し、ｎ層側に形成する場合はｎ電極２３が接した電流注入層

としてのｎコンタクト層１２、またはキャリア閉じ込めとしてのｎクラッド層１４として形成することが素子のＶｆ、閾値を低下させる上で最も好ましい傾向にある。また、実施形態２の素子と同様の構成を、ＬＥＤ素子に適用できることはいうまでもない（ただし、ＬＥＤ素子では、リッジ部は必要ない）。

【００７０】以上のように構成された実施形態２の窒化物半導体素子では、各層が形成された後、Ｈを含まない雰囲気、例えば、窒素雰囲気中で、４００℃以上、例えば７００℃でアニーリングを行うことが好ましく、これによって、ｐ型窒化物半導体層領域の各層をさらに低抵抗化することができるので、これによって、さらに閾値電圧を低くすることができる。

【００７１】また、実施形態２の窒化物半導体素子では、ｐ側コンタクト層１２の表面にＮｉとＡｕよりなるｐ電極２１がストライプ状に形成され、このｐ電極２１に対して左右対称にｎ側コンタクト層を露出させて、そのｎ側コンタクト層表面のほぼ全面にｎ電極２３を設けている。このように、絶縁性基板を用いた場合ｐ電極２１の両側に左右対称にｎ電極２３を設ける構造は、閾値電圧を低くする上で非常に有利である。

【００７２】なお、本実施形態２では、リッジ部（ストライプ状の電極）に垂直な方向で劈開した劈開面（共振器面）にSiO_2とTiO_2よりなる誘電体多層膜を形成してもよい。

【００７３】このように、本発明において、超格子層は、活性層を挟設するｎ型領域又はｐ型領域に形成されるキャリア閉じ込め層としてのクラッド層、活性層の光ガイド層、若しくは電極が接して形成される電流注入層として用いられるため、超格子層を構成する窒化物半導体の平均バンドギャップエネルギーが活性層よりも大きくなるように調整することが望ましい。

【００７４】

【実施例】以下、実施例において本発明を詳説する。

［実施例１］本発明に係る実施例１は図２に示す窒化物半導体素子（ＬＤ素子）の作成例であり、以下の手順で作製される。まず、サファイア（Ｃ面）よりなる基板１０を反応容器内にセットし、容器内を水素で十分置換した後、水素を流しながら、基板の温度を１０５０℃まで上昇させ、基板のクリーニングを行う。続いて、温度を５１０℃まで下げ、キャリアガスに水素、原料ガスにアンモニア（NH_3）とＴＭＧ（トリメチルガリウム）とを用い、基板１０上にＧａＮよりなる第１のバッファ層１１を約２００オングストロームの膜厚で成長させる。

【００７５】バッファ層１１成長後、ＴＭＧのみ止めて、温度を１０５０℃まで上昇させる。１０５０℃になったら、同じく原料ガスにＴＭＧ、アンモニアガスを用い、キャリア濃度$1\times10^{18}/cm^3$のアンドープＧａＮよりなる第２のバッファ層１１２を５μｍの膜厚で成長させる。第２のバッファ層は$In_XAl_YGa_{1-X-Y}N$（0≦X、0≦Y、X+Y≦1）で構成でき、その組成は特に問うものではないが、好ましくはアンドープでＡｌ（Y値）が０．１以下の$Al_YGa_{1-Y}N$、最も好ましくはアンドープのＧａＮとする。続いて、１０５０℃でＴＭＧ、アンモニア、不純物ガスにシランガス（SiH_4）を用い、Ｓｉを$1\times10^{19}/cm^3$ドープしたｎ型ＧａＮよりなるｎ側コンタクト層１２を１μｍの膜厚で成長させる。このｎ側コンタクト層１２は超格子で形成するとさらに好ましい。

【００７６】次に、温度を８００℃にして、原料ガスにＴＭＧ、ＴＭＩ（トリメチルインジウム）、アンモニア、不純物ガスにシランガスを用い、Ｓｉを$5\times10^{18}/cm^3$ドープした$In_{0.1}Ga_{0.9}N$よりなるクラック防止層１３を５００オングストロームの膜厚で成長させる。そして温度を１０５０℃にして、ＴＭＡ、ＴＭＧ、アンモニア、シランガスを用い、Ｓｉを$5\times10^{18}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を２０オングストロームの膜厚で成長させ、続いて、ＴＭＡ、シランを止め、アンドープＧａＮよりなる第２の層を２０オングストロームの膜厚で成長させる。そして、この操作をそれぞれ１００回繰り返し、総膜厚０．４μｍの超格子層よりなるｎ側クラッド層１４を成長させる。

【００７７】続いて、１０５０℃でＳｉを$5\times10^{18}/cm^3$ドープしたｎ型ＧａＮよりなるｎ側光ガイド層１５を０．１μｍの膜厚で成長させる。次に、ＴＭＧ、ＴＭＩ、アンモニア、シランを用いて活性層１６を成長させる。活性層１６は温度を８００℃に保持して、まずＳｉを$8\times10^{18}/cm^3$でドープした$In_{0.2}Ga_{0.8}N$よりなる井戸層を２５オングストロームの膜厚で成長させる。次にＴＭＩのモル比を変化させるのみで同一温度で、Ｓｉを$8\times10^{18}/cm^3$ドープした$In_{0.01}Ga_{0.99}N$よりなる障壁層を５０オングストロームの膜厚で成長させる。この操作を２回繰り返し、最後に井戸層を積層した総膜厚１７５オングストロームの多重量子井戸構造（ＭＱＷ）の活性層１６を成長させる。

【００７８】次に、温度を１０５０℃に上げ、原料ガスにＴＭＧ、ＴＭＡ、アンモニア、不純物ガスにCp_2Mg（シクロペンタジエニルマグネシウム）を用い、活性層よりもバンドギャップエネルギーが大きく、Ｍｇを$1\times10^{20}/cm^3$ドープしたｐ型$Al_{0.3}Ga_{0.7}N$よりなるｐ側キャップ層１７を３００オングストロームの膜厚で成長させる。続いて、１０５０℃で、バンドギャップエネルギーがｐ側キャップ層１７よりも小さい、Ｍｇを$1\times10^{20}/cm^3$ドープしたｐ型ＧａＮよりなるｐ側光ガイド層１８を０．１μｍの膜厚で成長させる。

【００７９】続いて、ＴＭＡ、ＴＭＧ、アンモニア、Cp_2Mgを用い、１０５０℃でＭｇを$1\times10^{20}/cm$

^{3}ドープしたｐ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を２０オングストロームの膜厚で成長させ、続いてＴＭＡのみを止め、Ｍｇを$1\times10^{20}/cm^{3}$ドープしたｐ型ＧａＮよりなる第２の層を２０オングストロームの膜厚で成長させる。そしてこの操作をそれぞれ１００回繰り返し、総膜厚０．４μｍの超格子層よりなるｐ側クラッド層１９を形成する。最後に、１０５０℃で、ｐ側クラッド層１９の上に、Ｍｇを$2\times10^{20}/cm^{3}$ドープしたｐ型ＧａＮよりなるｐ側コンタクト層２０を１５０オングストロームの膜厚で成長させる。

【００８０】反応終了後、温度を室温まで下げ、さらに窒素雰囲気中、ウェーハを反応容器内において、７００℃でアニーリングを行い、ｐ型層をさらに低抵抗化する。アニーリング後、ウェーハを反応容器から取り出し、図２に示すように、ＲＩＥ装置により最上層のｐ側コンタクト層２０と、ｐ側クラッド層１９とをエッチングして、４μｍのストライプ幅を有するリッジ形状とする。

【００８１】次にリッジ表面にマスクを形成し、図２に示すように、ストライプ状のリッジに対して左右対称にして、ｎ側コンタクト層１２の表面を露出させる。次にｐ側コンタクト層２０のストライプリッジ最表面のほぼ全面にＮｉとＡｕよりなるｐ電極２１を形成する。一方、ＴｉとＡｌよりなるｎ電極２３をストライプ状のｎ側コンタクト層３のほぼ全面に形成する。

【００８２】次に、図２に示すようにｐ電極２１と、ｎ電極２３との間に露出した窒化物半導体層の表面にSiO_2よりなる絶縁膜２５を形成し、この絶縁膜２５を介してｐ電極２１と電気的に接続したｐパッド電極２２、及びｎパッド電極２４を形成する。以上のようにして、ｎ電極とｐ電極とを形成したウェーハを研磨装置に移送し、ダイヤモンド研磨剤を用いて、窒化物半導体を形成していない側のサファイア基板１をラッピングし、基板の厚さを５０μｍとする。ラッピング後、さらに細かい研磨剤で１μｍポリシングして基板表面を鏡面状とする。

【００８３】基板研磨後、研磨面側をスクライブして、ストライプ状の電極に垂直な方向でバー状に劈開し、劈開面に共振器を作製する。共振器面にSiO_2とTiO_2よりなる誘電体多層膜を形成し、最後にｐ電極に平行な方向で、バーを切断してレーザチップとした。次にチップをフェースアップ（基板とヒートシンクとが対向した状態）でヒートシンクに設置し、それぞれの電極をワイヤーボンディングして、室温でレーザ発振を試みたところ、室温において、閾値電流密度２．９ｋＡ／cm^{2}、閾値電圧４．４Ｖで、発振波長４０５ｎｍの連続発振が確認され、５０時間以上の寿命を示した。

【００８４】（比較例１）一方、第２のバッファ層１１２を成長させず、さらにｎ側コンタクト層１２をＳｉを$1\times10^{19}/cm^{3}$ドープしたｎ型ＧａＮ単一で５μｍ成長させ、ｎ側クラッド層１４をＳｉを$1\times10^{19}/cm^{3}$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$単一で０．４μｍ成長させ、ｐ側クラッド層１９をＭｇを$1\times10^{20}/m^{3}$ドープしたｐ型$Al_{0.2}Ga_{0.8}N$単一で０．４μｍ成長させ、さらにｐ側コンタクト層２０をＭｇを$2\times10^{20}/cm^{3}$ドープした単一のｐ型ＧａＮを０．２μｍ成長させる他は実施例１と同様にしてレーザ素子を得た。つまり基本構成として、表１に示すように構成する。

【００８５】

【表１】

基板	１０・・・サファイア	
バッファ層	１１・・・ＧａＮ	２００Å
nコンタクト層	１２・・・Ｓｉドープn型ＧａＮ Si:１×１０^{19}／cm^3	５μm
クラック防止層	１３・・・Ｓｉドープn型Ｉｎ0.1Ｇａ0.9N Si:５×１０^{18}／cm^3	５００Å
nクラッド層	１４・・・Ｓｉドープn型Ａｌ0.2Ｇａ0.8N Si:５×１０^{18}／cm^3	０．５μm
n光ガイド層	１５・・・Ｓｉドープn型ＧａＮ Si:５×１０^{18}／cm^3	０．１μm
活性層(MQW) （総膜厚１７５Å）	１６・・・ＳｉドープＩｎ0.2Ｇａ0.8N ＳｉドープＩｎ0.01Ｇａ0.95N Si:８×１０^{18}／cm^3	２５Å ５０Å
キャップ層	１７・・・Ｍｇドープp型Ａｌ0.1Ｇａ0.9N Mg:１×１０^{20}／cm^3	３００Å
p光ガイド層	１８・・・Ｍｇドープp型ＧａＮ Mg:１×１０^{20}／cm^3	０．１μm
pクラッド層	１９・・・Ｍｇドープp型Ａｌ0.2Ｇａ0.8N Mg:１×１０^{20}／cm^3	０．５μm
pコンタクト層	２０・・・Ｍｇドープp型ＧａＮ Mg:２×１０^{20}／cm^3	０．２μm

【００８６】このように構成した比較例のレーザ素子は、閾値電流密度７ｋＡ／cm^2 で連続発振が確認されたが、閾値電圧は８．０Ｖ以上あり、数分で切れてしまった。

【００８７】［実施例２］実施例１において、ｎ側コンタクト層１２を、Ｓｉを２×１０^{19} ／cm^3 ドープしたｎ型$Al_{0.05}Ga_{0.95}N$よりなる第１の層を３０オングストロームの膜厚で成長させ、続いて、アンドープのＧａＮよりなる第２の層を３０オングストロームの膜厚で成長させて、これを繰り返し、総膜厚１．２μmの超格子構造とする。それ以外の構造は実施例１と同様の構造を有するレーザ素子としたところ、閾値電流密度２．７ｋＡ／cm^2 、閾値電圧４．２Ｖで、寿命も６０時間以上を示した。

【００８８】［実施例３］実施例２において、ｎ側コンタクト層１２を構成する超格子において、第２の層をＳｉを１×１０^{18} ／cm^3 ドープしたＧａＮとする他は、実施例２と同様の構造を有するレーザ素子を作製したところ、実施例２とほぼ同等の特性を有するレーザ素子が得られた。

【００８９】［実施例４］実施例１において、第２のバッファ層１１２を、Ｓｉを１×１０^{17} ／cm^3 ドープしたＧａＮとして、４μm成長させる他は、実施例１と同様の構造を有するレーザ素子を作製したところ、閾値電流密度２．９ｋＡ／cm^2 、閾値電圧４．５Ｖに上昇したが、寿命は５０時間以上を示した。

【００９０】［実施例５］実施例１において、ｎ側コンタクト層１２を、Ｓｉを２×１０^{19} ／cm^3 ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を６０オングストロームの膜厚で成長させ、続いて、Ｓｉを１×１０^{19} ／cm^3 ドープしたＧａＮよりなる第２の層を４０オングストロームの膜厚で成長させて、順次これを繰り返し、総膜厚２μmの超格子構造とする。そして、ｎ側クラッド層１４をＳｉを１×１０^{19} ／cm^3 ドープしたｎ型$Al_{0.2}Ga_{0.8}N$単一で０．４μm成長させる。それ以外の構造は実施例１と同様の構造を有するレーザ素子としたところ、閾値電流密度３．２ｋＡ／cm^2 、閾値電圧４．８Ｖで、寿命も３０時間以上を示した。

【００９１】［実施例６］実施例６は、実施例１と比較して、以下の（１）、（２）が異なる他は、実施例１と同様に構成される。

（１）バッファ層１１成長後、ＴＭＧのみ止めて、温度を１０５０℃まで上昇させる。１０５０℃になったら、原料ガスにＴＭＡ、ＴＭＧ、アンモニア、シランを用い、Ｓｉを１×１０^{19} ／cm^3 ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を６０オングストロームの膜厚で成長させ、続いて、シラン、ＴＭＡを止めアンドープのＧａＮよりなる第２の層を４０オングストロームの膜厚で成長させる。そして第１層＋第２層＋第１層＋第２層＋・・・というように超格子層を構成し、それぞれ第１の層を５００層、第２の層を５００層交互に積層し、総膜厚５μmの超格子よりなるｎ側コンタクト層１２を形成する。

（２）次に、実施例１と同様にして、Ｓｉを５×１０^{18} ／cm^3 ドープした$In_{0.1}Ga_{0.9}N$よりなるクラック防止層１３を５００オングストロームの膜厚で成長させる。そして、温度を１０５０℃にして、ＴＭＡ、ＴＭＧ、アンモニア、シランを用い、Ｓｉを５×１０^{18} ／cm^3 ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よ

りなるｎ側クラッド層１４を０．５μｍの膜厚で成長させる。後の、ｎ側クラッド層１４から上は、実施例１のレーザ素子と同様の構造を有するレーザ素子とする。つまり表１の基本構造において、ｎ側コンタクト層１２、及びｐ側クラッド層１９を超格子とし、ｐ側コンタクト層２０の膜厚を実施例１のように１５０オングストロームとするレーザ素子を作製する。このレーザ素子は閾値電流密度３．２ｋＡ／cm^2、閾値電圧４．８Ｖで、４０５ｎｍの連続発振が確認され、寿命も３０時間以上を示した。

【００９２】さらに、実施例６の構造のＬＤ素子のｐ側コンタクト層の膜厚を順次変更した際、そのｐ側コンタクト層の膜厚と、ＬＤ素子の閾値電圧との関係を図３に示す。これはｐ側コンタクト層が、左から順にＡ（１０オングストローム以下）、Ｂ（１０オングストローム）、Ｃ（３０オングストローム）、Ｄ（１５０オングストローム、本実施例）、Ｅ（５００オングストローム）、Ｆ（０．２μｍ）、Ｇ（０．５μｍ）、Ｈ（０．８μｍ）の場合の閾値電圧を示している。この図に示すように、ｐ側コンタクト層の膜厚が５００オングストロームを超えると閾値電圧が次第に上昇する傾向にある。ｐ側コンタクト層２０の膜厚は５００オングストローム以下、さらに好ましくは３００オングストローム以下であることが望ましい。なお１０オングストローム以下（およそ１原子層、２原子層近く）になると、下部のｐ側クラッド層１９の表面が露出してくるため、ｐ電極のコンタクト抵抗が悪くなり、閾値電圧は上昇する傾向にある。しかしながら、本発明のＬＤ素子では超格子層を有しているために、閾値電圧が比較例のものに比べて大幅に低下している。

【００９３】（比較例２）表１の構成のレーザ素子において、ｎ側クラッド層１４をＳｉを$1\times10^{19}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を１８０オングストロームの膜厚で成長させ、続いてアンドープのＧａＮよりなる第２の層を１２０オングストロームの膜厚で成長させ、総膜厚０．６μｍの多層膜とする。つまり第１の層と第２の層の膜厚を厚くした構造で構成してレーザ素子を作製したところ、閾値電流密度６．５ｋＡ／cm^2で連続発振が確認され、閾値電圧が７．５Ｖであった。なおこのレーザ素子は数分で切れてしまった。

【００９４】［実施例７］実施例６において、ｐ側クラッド層１９をＭｇを$1\times10^{20}/cm^3$ドープした$Al_{0.2}Ga_{0.8}N$、６０オングストロームよりなる第１の層と、Ｍｇを$1\times10^{20}/cm^3$ドープしたｐ型ＧａＮ、４０オングストロームよりなる第２の層とを積層した総膜厚０．５μｍの超格子構造とする他は実施例６と同様のレーザ素子を作製する。つまり、実施例６のｐ側クラッド層１９を構成する超格子層の膜厚を変える他は同様にしてレーザ素子を作製したところ、閾値電圧が実施例６のレーザ素子に比較して若干上昇する傾向にあったが、２０時間以上の寿命を示した。

【００９５】［実施例８］実施例７において、さらにｎ側クラッド層１４をＳｉを$1\times10^{19}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$、６０オングストロームよりなる第１の層と、Ｓｉを$1\times10^{19}/cm^3$ドープしたｎ型ＧａＮ、４０オングストロームよりなる第２の層とを積層した総膜厚０．５μｍの超格子構造とする他は実施例７と同様のレーザ素子を作製する。つまり、実施例６のｎ側コンタクト層１２、ｐ側クラッド層１９に加えてｎ側クラッド層を超格子としたレーザ素子は、実施例６とほぼ同等の特性を有していた。

【００９６】［実施例９］実施例１において、第２のバッファ層１１２を成長させずに、表１に示すように、第１のバッファ層１１の上に、直接ｎ側コンタクト層１２としてＳｉを$1\times10^{19}/cm^3$ドープしたｎ型ＧａＮ層を５μｍ成長させる。その他は、実施例１と同様の構造を有するレーザ素子とする。つまり、表１の基本構造において、ｎ側クラッド層１４を２０オングストロームのＳｉ（$1\times10^{19}/cm^3$）ドープｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層と、２０オングストロームのアンドープＧａＮよりなる第２の層とを積層してなる総膜厚０．４μｍの超格子構造とする。さらにｐ側クラッド層１９を２０オングストロームのＭｇ（$1\times10^{20}/cm^3$）ドープｐ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層と、２０オングストロームのＭｇ（$1\times10^{20}/cm^3$）ドープｐ型ＧａＮよりなる第２の層とを積層してなる総膜厚０．４μｍの超格子構造とする。さらにまたｐ側コンタクト層２０を実施例１のように１５０オングストロームのＭｇ（$2\times10^{20}/cm^3$）ドープｐ型ＧａＮとしたところ、閾値電流密度３．３ｋＡ／cm^2で、４０５ｎｍの連続発振が確認され、閾値電圧は５．０Ｖ、寿命も３０時間以上を示した。

【００９７】［実施例１０］実施例９において、ｎ側クラッド層１４の超格子を構成する第２の層を、Ｓｉを$1\times10^{17}/cm^3$ドープしたＧａＮとする他は、実施例９と同様のレーザ素子を作製する。つまりバンドギャップエネルギーの大きい方の層に、Ｓｉを多くドープする他は、実施例９と同様にして作製したレーザ素子は、実施例９とほぼ同等の特性を示した。

【００９８】［実施例１１］実施例９において、ｎ側クラッド層１４を構成する第２の層を、Ｓｉを$1\times10^{19}/cm^3$ドープしたｎ型$In_{0.01}Ga_{0.99}N$とする他は同様にしてレーザ素子を作製する。つまりｎ側クラッド層１４の超格子を構成する第２の層の組成をＩｎＧａＮとし、第１の層と第２の層との不純物濃度を同じにする他は、実施例９と同様にして作製したレーザ素子は、実施例９とほぼ同等の特性を示した。

【００９９】［実施例１２］実施例９において、ｎ側クラッド層１４を構成する第１の層（Ｓｉ：1×10^{19}

$/cm^3$ ドープ$Al_{0.2}Ga_{0.8}N$）の膜厚を６０オングストロームとし、第２の層をＳｉを$1\times10^{19}/cm^3$ドープした４０オングストロームのＧａＮとし、総膜厚０．５μｍの超格子構造とする。さらにｐ側クラッド層１９を構成する第１の層（Ｍｇ：$1\times10^{20}/cm^3$ドープ$Al_{0.2}Ga_{0.8}N$）の膜厚を６０オングストロームとし、第２の層（Ｍｇ：$1\times10^{20}/cm^3$ドープ：ＧａＮ）の膜厚を４０オングストロームとし、総膜厚０．５μｍの超格子構造とする。つまりｎ側クラッド層１４を構成する第１の層と第２の層のドープ量を同じにして、膜厚を変化させ、ｐ側クラッド層１９を構成する第１の層と第２の層との膜厚を変化させる他は、実施例９と同様にしてレーザ素子を作製したところ、閾値電流密度３．４ｋＡ／cm^2で、４０５ｎｍの連続発振が確認され、閾値電圧は５．２Ｖ、寿命も２０時間以上を示した。

【０１００】［実施例１３］実施例１１において、ｎ側クラッド層１４を構成する第２の層（ＧａＮ）のＳｉ濃度を$1\times10^{17}/cm^3$とする他は実施例１１と同様の構造を有するレーザ素子を作製したところ、実施例１１とほぼ同等の特性を有するレーザ素子が作製できた。

【０１０１】［実施例１４］実施例１１において、ｎ側クラッド層１４を構成する第２の層（ＧａＮ）をアンドープとする他は実施例１１と同様の構造を有するレーザ素子を作製したところ、実施例１１とほぼ同等の特性を有するレーザ素子が作製できた。

【０１０２】［実施例１５］実施例９において、ｎ側クラッド層１４をＳｉを$1\times10^{19}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$単一で０．４μｍ成長させる他は同様にしてレーザ素子を作製する。つまり、表１の基本構造において、ｐ側クラッド層１９のみを実施例１のようにＭｇを$1\times10^{20}/cm^3$ドープしたｐ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層、２０オングストロームと、Ｍｇを$1\times10^{19}/cm^3$ドープしたｐ型ＧａＮよりなる第２の層２０オングストロームとからなる総膜厚０．４μｍの超格子構造とし、さらに、ｐ側コンタクト層２０を実施例１のように１５０オングストロームのＭｇ（$2\times10^{20}/cm^3$）ドープｐ型ＧａＮとしたところ、同じく閾値電流密度３．４ｋＡ／cm^2で、４０５ｎｍの連続発振が確認され、閾値電圧は５．１Ｖ、寿命は２０時間以上を示した。

【０１０３】［実施例１６］実施例１５において、ｐ側クラッド層１９を構成する超格子層の膜厚を第１の層（$Al_{0.2}Ga_{0.8}N$）を６０オングストロームとし、第２の層（ＧａＮ）を４０オングストロームとして積層し、総膜厚０．５μｍとする他は実施例１４と同様のレーザ素子を得たところ、閾値電圧は若干上昇する傾向にあったが、寿命は２０時間以上あった。

【０１０４】［実施例１７］実施例９において、ｐ側クラッド層１９をＭｇを$1\times10^{20}/cm^3$ドープしたｐ型$Al_{0.2}Ga_{0.8}N$単一で０．４μｍ成長させる他は同様にしてレーザ素子を作製する。つまり、表１の基本構造において、ｎ側クラッド層１４のみを実施例１のようにＳｉを$1\times10^{19}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層、２０オングストロームと、アンドープのＧａＮよりなる第２の層２０オングストロームとからなる総膜厚０．４μｍの超格子構造とし、さらに、ｐ側コンタクト層２０を実施例１のように１５０オングストロームのＭｇ（$2\times10^{20}/cm^3$）ドープｐ型ＧａＮとしたところ、同じく閾値電流密度３．５ｋＡ／cm^2で、４０５ｎｍの連続発振が確認され、閾値電圧は５．４Ｖ、寿命は１０時間以上を示した。

【０１０５】［実施例１８］実施例１７において、ｎ側クラッド層１４を構成する超格子層の膜厚を第１の層（$Al_{0.2}Ga_{0.8}N$）を７０オングストロームとし、第２の層をＳｉを$1\times10^{19}/cm^3$ドープした$In_{0.01}Ga_{0.99}N$、７０オングストロームとして積層し、総膜厚０．４９μｍとする他は実施例１７と同様のレーザ素子を得たところ、実施例１６に比べて閾値電圧が若干上昇する傾向にあったが、同じく１０時間以上の寿命を有するレーザ素子が得られた。

【０１０６】［実施例１９］実施例１７において、ｎ側クラッド層１４を構成する超格子層の膜厚を第１の層（$Al_{0.2}Ga_{0.8}N$）を６０オングストロームとし、第２の層（アンドープＧａＮ）を４０オングストロームとして積層し、総膜厚０．５μｍとする他は実施例１６と同様のレーザ素子を得たところ、実施例１７に比べて閾値電圧が若干上昇する傾向にあったが、同じく１０時間以上の寿命を有するレーザ素子が得られた。

【０１０７】［実施例２０］実施例９において、さらにｎ側光ガイド層１５をアンドープのＧａＮよりなる第１の層、２０オングストロームと、アンドープの$In_{0.1}Ga_{0.9}N$よりなる第２の層、２０とを積層してなる総膜厚８００オングストロームの超格子層とする。それに加えて、ｐ側光ガイド層１８もアンドープのＧａＮよりなる第１の層、２０オングストロームと、アンドープの$In_{0.1}Ga_{0.9}N$よりなる第２の層、２０オングストロームとを積層してなる総膜厚８００オングストロームの超格子構造とする。つまり、表１の基本構造において、ｎ側クラッド層１４、ｎ側光ガイド層１５、ｐ側光ガイド層１８、及びｐ側クラッド層１９とを超格子構造とし、さらにまたｐ側コンタクト層２０を実施例１のように１５０オングストロームのＭｇ（$2\times10^{20}/cm^3$）ドープｐ型ＧａＮとしたところ、閾値電流密度２．９ｋＡ／cm^2で、４０５ｎｍの連続発振が確認され、閾値電圧は４．４Ｖ、寿命も６０時間以上を示した。

【０１０８】［実施例２１］本実施例は図１のＬＥＤ素子を元に説明する。実施例１と同様にしてサファイアよ

りなる基板１の上にＧａＮよりなるバッファ層２を２００オングストロームの膜厚で成長させ、次いでＳｉを$1\times10^{19}/cm^3$ドープしたｎ型ＧａＮよりなるコンタクト層を５μｍの膜厚で成長させ、次に$In_{0.4}Ga_{0.6}N$よりなる膜厚３０オングストロームの単一量子井戸構造よりなる活性層４を成長させる。

【０１０９】（ｐ側超格子層）次に、実施例１と同様にして、Ｍｇを$1\times10^{20}/cm^3$ドープしたｐ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を２０オングストロームの膜厚で成長させ、続いてＭｇを$1\times10^{19}/cm^3$ドープしたｐ型ＧａＮよりなる第２の層を２０オングストロームの膜厚で成長させ、総膜厚０．４μｍの超格子よりなるｐ側クラッド層５を成長させる。このｐ側クラッド層４の膜厚も特に限定しないが、１００オングストローム以上、２μm以下、さらに好ましくは５００オングストローム以上、１μm以下で成長させることが望ましい。

【０１１０】次にこのｐ側クラッド層５の上にＭｇを$1\times10^{20}/cm^3$ドープしたｐ型ＧａＮ層を０．５μｍの膜厚で成長させる。成長後、ウェーハを反応容器から取り出し実施例１と同様にして、アニーリングを行った後、ｐ側コンタクト層６側からエッチングを行いｎ電極９を形成すべきｎ側コンタクト層３の表面を露出させる。最上層のｐ側コンタクト層６のほぼ全面に膜厚２００オングストロームのＮｉ－Ａｕよりなる透光性のｐ電極７を形成し、その全面電極７の上にＡｕよりなるｐパッド電極８を形成する。露出したｎ側コンタクト層の表面にもＴｉ－Ａｌよりなるｎ電極９を形成する。

【０１１１】以上のようにして電極を形成したウェーハを３５０μm角のチップに分離してＬＥＤ素子としたところ、Ｉｆ２０ｍＡにおいて５２０ｎｍの緑色発光を示し、Ｖｆは３．２Ｖであった。これに対し、ｐ側クラッド層５を単一のＭｇドープ$Al_{0.2}Ga_{0.8}N$で構成したＬＥＤ素子のＶｆは３．４Ｖであった。さらに静電耐圧は本実施例の方が２倍以上の静電耐圧を有していた。

【０１１２】［実施例２２］実施例２１において、ｐ側クラッド層５を構成する超格子層を、第１の層の膜厚を５０オングストロームとし、第２の層をＭｇを$1\times10^{20}/cm^3$ドープしたＧａＮ、５０オングストロームとして、それぞれ２５層積層し、総膜厚０．２５μｍの超格子とする他は同様にしてＬＥＤ素子を作成したところ、実施例２１とほぼ同等の特性を有するＬＥＤ素子が得られた。

【０１１３】［実施例２３］実施例２１において、ｐ側クラッド層５を構成する超格子層の厚さを、第１の層１００オングストローム、第２の層を７０オングストロームの膜厚として、総膜厚０．２５μｍの超格子とする他は同様にしてＬＥＤ素子を作成したところ、Ｖｆは３．４Ｖであったが、静電耐圧は従来のものよりも２０％以上優れていた。

【０１１４】［実施例２４］実施例２１において、ｎ側コンタクト層３を成長させる際、Ｓｉを$2\times10^{19}/cm^3$ドープしたｎ型$Al_{0.2}Ga_{0.8}N$よりなる第１の層を６０オングストローム、アンドープのＧａＮよりなる第２の層を４０オングストロームの膜厚で成長させ、それぞれ第１の層を５００層、第２の層を５００層交互に積層し、総膜厚５μｍの超格子とする。その他は実施例１２と同様にしてＬＥＤ素子を作製したところ、同じくＩｆ２０ｍＡにおいて、Ｖｆは３．１Ｖに低下し、静電耐圧は従来に比較比較して２．５倍以上に向上した。

【０１１５】［実施例２５］実施例２３において、ｐ側クラッド層５を構成する超格子の第１の層（$Al_{0.2}Ga_{0.8}N$）の膜厚を６０オングストロームとし、第２の層の膜厚を４０オングストロームとして、それぞれ２５層交互に積層して、総膜厚０．３μｍとする他は同様の構造を有するＬＥＤ素子を作製したところ、Ｖｆは３．２Ｖで、静電耐圧は従来の２倍以上であった。

【０１１６】［実施例２６］本実施例は図４に示すレーザ素子を基に説明する。図４も、図２と同様にレーザ光の共振方向に垂直な方向で素子を切断した際の断面図であるが、図２と異なるところは、基板１０にＧａＮよりなる基板１０１を用いているところと、第２のバッファ層１１２を成長させずに、ｎ型不純物をドープした第３のバッファ層１１３を成長させているところにある。この図４に示すレーザ素子は以下の方法によって得られる。

【０１１７】まずサファイア基板上にＭＯＶＰＥ法、若しくはＨＶＰＥ法を用いて、Ｓｉを$5\times10^{18}/cm^3$ドープしたＧａＮ層を厚さ３００μｍで成長させた後、サファイア基板を除去して厚さ３００μｍのＳｉドープＧａＮ基板１０１を作製する。ＧａＮ基板１０１は、このように窒化物半導体と異なる基板の上に、例えば１００μｍ以上の膜厚で成長させた後、その異種基板を除去することによって得られる。ＧａＮ基板１０１はアンドープでも良いし、またｎ型不純物をドープして作製しても良い。ｎ型不純物をドープする場合には通常$1\times10^{17}/cm^3\sim1\times10^{19}/cm^3$の範囲で不純物をドープすると結晶性の良いＧａＮ基板が得られる。

【０１１８】ＧａＮ基板１０１作製後、温度を１０５０℃にして、Ｓｉを$3\times10^{18}/cm^3$ドープしたｎ型ＧａＮよりなる第３のバッファ層１１３を３μｍの膜厚で成長させる。なお第３のバッファ層１１３は図１、図２においてｎ側コンタクト層１４に相当する層であるが、電極を形成する層ではないので、ここではコンタクト層とは言わず、第３のバッファ層１１３という。なおＧａＮ基板１０１と第３のバッファ層１１３との間に、実施例１と同様にして低温で成長させる第１のバッファ層を成長させても良いが、第１のバッファ層を成長させる場

合には、３００オングストローム以下にすることが望ましい。

【０１１９】次に第３のバッファ層１１３の上に、実施例１と同様にＳｉを５×１０^{18} ／cm^{3} ドープしたＩｎ$_{0.1}$ Ｇａ$_{0.9}$ Ｎよりなるクラック防止層１３を５００オングストロームの膜厚で成長させる。次に、Ｓｉを５×１０^{18} ／cm^{3} ドープしたｎ型Ａｌ$_{0.2}$ Ｇａ$_{0.8}$ Ｎよりなる第１の層、２０オングストロームと、Ｓｉを５×１０^{18} ／cm^{3} ドープしたＧａＮよりなる第２の層２０オングストロームとを１００回交互に積層した、総膜厚０．４μmの超格子層よりなるｎ側クラッド層１４を成長させる。次に実施例１と同様に、Ｓｉを５×１０^{18} ／cm^{3} ドープしたｎ型ＧａＮよりなるｎ側光ガイド層１５を０．１μmの膜厚で成長させる。

【０１２０】次に、アンドープＩｎ$_{0.2}$ Ｇａ$_{0.8}$ Ｎよりなる井戸層、２５オングストロームと、アンドープＧａＮよりなる障壁層５０オングストロームとを成長させ、交互に２回繰り返し、最後に井戸層を積層した総膜厚１７５オングストロームの多重量子井戸構造（ＭＱＷ）の活性層１６を成長させる。

【０１２１】次に、実施例１と同様に、Ｍｇを１×１０^{20} ／cm^{3} ドープしたｐ型Ａｌ$_{0.3}$ Ｇａ$_{0.7}$ Ｎよりなるｐ側キャップ層１７を３００オングストロームの膜厚で成長させ、Ｍｇを１×１０^{20} ／cm^{3} ドープしたｐ型ＧａＮよりなるｐ側光ガイド層１８を０．１μmの膜厚で成長させる。

【０１２２】次に実施例１と同様にして、Ｍｇを１×１０^{20} ／cm^{3} ドープしたｐ型Ａｌ$_{0.2}$ Ｇａ$_{0.8}$ Ｎよりなる第１の層、２０オングストロームと、Ｍｇを１×１０^{20} ／cm^{3} ドープしたｐ型ＧａＮよりなる第２の層、２０オングストロームよりなる、総膜厚０．４μmの超格子層よりなるｐ側クラッド層１９を形成し、最後に、ｐ側クラッド層１９の上に、Ｍｇを２×１０^{20} ／cm^{3} ドープしたｐ型ＧａＮよりなるｐ側コンタクト層２０を１５０オングストロームの膜厚で成長させる。

【０１２３】反応終了後、７００℃でアニーリングした後、実施例１と同様に、ＲＩＥ装置により最上層のｐ側コンタクト層２０と、ｐ側クラッド層１９とをエッチングして、４μmのストライプ幅を有するリッジ形状とする。

【０１２４】次に、実施例１と同じくｐ側コンタクト層２０のストライプリッジ最表面のほぼ全面にＮｉとＡｕよりなるｐ電極２１を形成し、ＧａＮ基板１０１の裏面のほぼ全面に、ＴｉとＡｌよりなるｎ電極２３を形成する。

【０１２５】次に、図４に示すようにｐ電極２１の面積を除く、ｐ側クラッド層１９のSiO_2よりなる絶縁膜２５を形成し、この絶縁膜２５を介して、ｐ電極２１と電気的に接続したｐパッド電極２２を形成する。

【０１２６】電極形成後、ｐ電極２１に垂直な方向でＧａＮ基板１０１をバー状に劈開し、劈開面に共振器を作製する。なおＧａＮ基板の劈開面はM面とする。劈開面にSiO_2とTiO_2よりなる誘電体多層膜を形成し、最後にｐ電極に平行な方向で、バーを切断して図４に示すレーザチップとした。次にチップをフェースアップ（基板とヒートシンクとが対向した状態）でヒートシンクに設置し、ｐパッド電極２２をワイヤーボンディングして、室温でレーザ発振を試みたところ、室温において、閾値電流密度２．５ｋＡ／cm^{2} 、閾値電圧４．０Ｖで、発振波長４０５ｎｍの連続発振が確認され、５００時間以上の寿命を示した。これは基板にＧａＮを使用したことにより、結晶欠陥の広がりが少なくなったことによる。

【０１２７】

【発明の効果】以上説明したように、本発明に係る窒化物半導体素子は、活性層以外のｐ型窒化物半導体領域又はｎ型窒化物半導体領域において、超格子層を用いて構成しているので、電力効率を極めて良くすることができる。すなわち、従来の窒化物半導体素子では、活性層を多重量子井戸構造とすることは提案されていたが、活性層を挟む、例えばクラッド層等は単一の窒化物半導体層で構成されているのが通常であった。しかし、本発明の窒化物半導体素子では量子効果が出現するような層を有する超格子層をクラッド層、若しくは電流を注入するコンタクト層として設けているため、クラッド層側の抵抗率を低くすることができる。これによって、例えばＬＤ素子の閾値電流、閾値電圧を低くでき、該素子を長寿命とすることができる。さらに従来のＬＥＤは静電気に弱かったが、本発明では静電耐圧に強い素子を実現できる。このようにＶｆ、閾値電圧が低くできるので、発熱量も少なくなり、該素子の信頼性も向上させることができる。本発明の窒化物半導体素子によれば、ＬＥＤ、ＬＤ等の発光素子はもちろんのこと、窒化物半導体を用いた太陽電池、光センサー、トランジスタ等に利用すると非常の効率の高いデバイスを実現することが可能となりその産業上の利用価値は非常に大きい。

【図面の簡単な説明】

【図１】　本発明に係る実施形態１の窒化物半導体素子（ＬＥＤ素子）の構成を示す模式断面図である。

【図２】　本発明に係る実施形態２の窒化物半導体素子（ＬＤ素子）の構成を示す模式断面図である。

【図３】　本発明に係る実施例１のＬＤ素子におけるｐ側コンタクト層の膜厚と、閾値電圧との関係を示すグラフである。

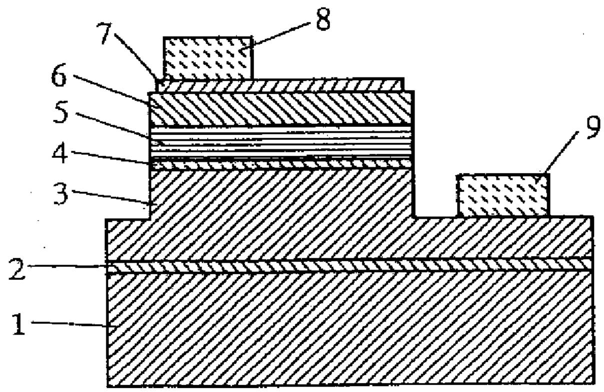
【図４】　本発明に係る実施例２６のＬＤ素子の模式断面図である。

【符号の説明】

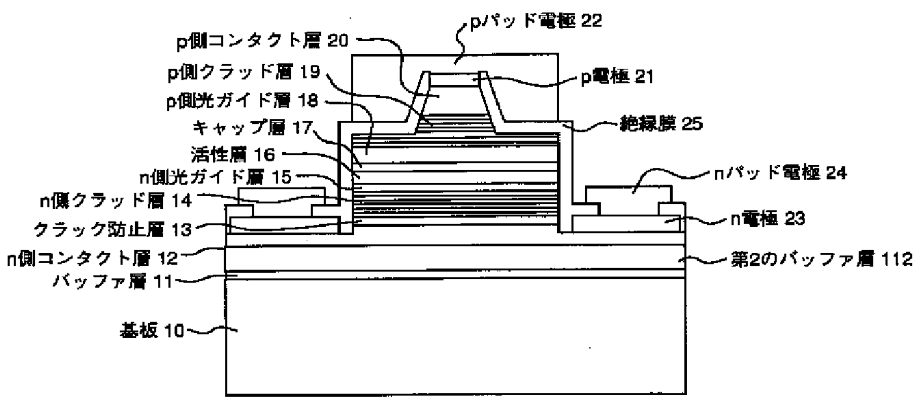
１、１０・・・・基板、
２、１１・・・・バッファ層、
３、１２・・・・ｎ側コンタクト層、

１３・・・・クラック防止層、
１４・・・・ｎ側クラッド層（超格子層）、
１５・・・・ｎ側光ガイド層、
４、１６・・・・活性層、
１７・・・・キャップ層、
１８・・・・ｐ側光ガイド層、
５、１９・・・・ｐ側クラッド層（超格子層）、
６、２０・・・・ｐ側コンタクト層、
＊７、２１・・・・ｐ電極、
８、２２・・・・ｐパッド電極、
９、２３・・・・ｎ電極、
２４・・・・ｎパッド電極、
２５・・・・絶縁膜、
１０１・・・・ＧａＮ基板、
１１２・・・・第２のバッファ層、
＊ １１３・・・・第３のバッファ層。

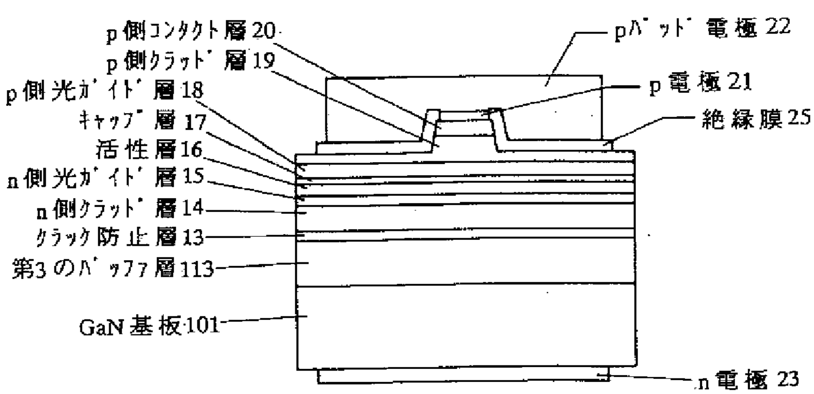
【図１】



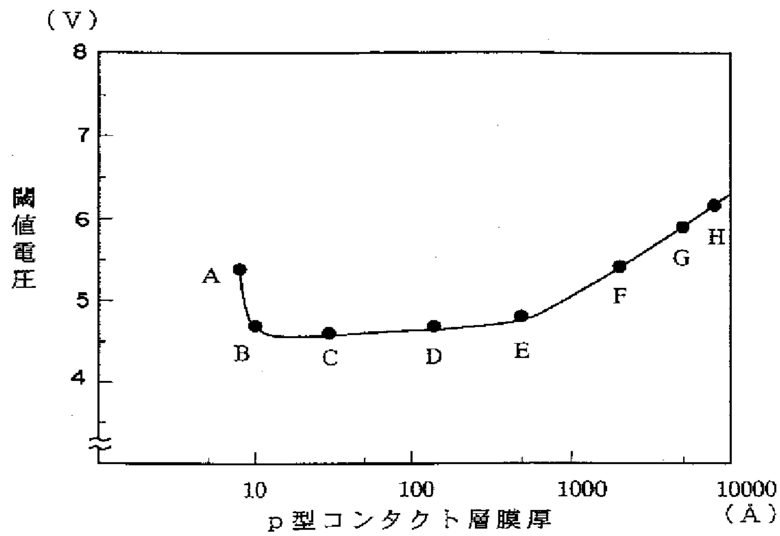
【図２】



【図４】



【図３】



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